ECONOMIC DISEASES *of* FIELD CROPS IN MANITOBA[1]

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THE HONOURABLE JOHN BRACKEN,
Premier of Manitoba.

SIR,

I have the honour to submit herewith a report on Economic Diseases of Field Crops in Manitoba, being Project No. 16 under the Economic Survey, and seventeenth in a series of reports covering many phases of the economic and social life of the province. This report is the work of J. H. Craigie, Dominion Laboratory of Plant Pathology, Winnipeg, Man.

I have the honour to be,
Sir,
Your obedient servant,
H. C. GRANT,
Acting Director.

Winnipeg, Manitoba,
February 16, 1939.

TABLE OF CONTENTS

INTRODUCTION

One of the chief hazards that beset the farmers of Manitoba in the production of their crops, is that incident to plant disease. Here the term plant disease is used in its restricted sense, and refers to ill health in plants caused by parasitic fungi, bacteria, and viruses, not to injury caused by insects or other plant pests. Practically every kind of crop is affected to a greater or less extent by one or more diseases. During the last twenty or twenty-five years, losses due to plant disease in Manitoba have probably been greater than those from any other natural cause.

Owing to the wide use of fungicides, such as are used for treating seed of numerous crops, and for sprays and dusts to protect vegetable and fruit crops, as well as of other preventive measures, the damage done by many different diseases has been greatly reduced in recent times. If such preventive measures were discontinued, the losses from these diseases, now held to a considerable extent in check, would increase many fold.

Against certain diseases, such as the cereal rusts, preventive measures are effective but they involve difficulty owing to the extensive area over which prevention needs to be practiced. Except in so far as losses from them have been avoided by the growing of resistant or partially resistant varieties, the province has suffered the full extent of damage possible under the conditions that prevailed.

Influence of Environment. The prevalence and severity of plant diseases vary considerably from season to season. This variation is less evident in those diseases against which preventive measures are regularly used than in those not readily controlled by such means. The variation is largely due to environmental factors, such as weather and soil conditions. Although a diseased condition in plants, for example, heat canker of flax, may result from environmental conditions, yet parasitic organisms or viruses, and not the environmental conditions, are primarily responsible for most of the common diseases of plants. Under Manitoba conditions, some diseases are destructive, especially in certain years when conditions favour their development; while some other diseases are of little or no consequence owing, at least, in part, to the check put upon them by prevailing weather conditions. A few diseases are absent or are of rare occurrence because of the absence of conditions that would make their development possible.

Relative Importance of Different Field Crops in Manitoba. The economic importance of any disease is largely determined by the economic importance of the crops that it attacks, and, of course, by the extent of the damage that it causes. A disease that damages seriously a valuable and widely-grown crop is of greater importance than one that damages equally badly a valuable crop that is only grown to a limited extent. In Manitoba, agriculture is largely devoted to the production of field crops, and, consequently, it is with diseases of these crops that the present report deals. Before giving consideration to any particular disease, it may be well, for the sake of indicating the relative importance of the principal field crops, to present the acreage and value of the several crops in this province.

Table 1 gives, for the period 1928 to 1937, the average acreage under crop and the average value of the respective field crops. The figures are taken or compiled from the Crop Bulletins issued by the Manitoba Department of Agriculture. In the table, clovers, alfalfa, and hay (excluding wild hay) are grouped together as hay crops; and peas, roots, buckwheat, etc., as miscellaneous crops.

It is seen from Table 1 that, during the ten-year period ending 1937, the average area under field crops in Manitoba was about 6,219,000 acres. Of this acreage, the average sown to cereal crops (wheat, oats, barley and rye) was 5,616,000 acres. Cereals, therefore, occupied slightly more than 90 per cent. of the land devoted to field crops. Out of a total average value of $56,172,000.00 for all field crops, the value of cereals is $47,803,000.00, or just over 85 per cent. of the total.

Table 1—The average yearly acreage under crop and the average yearly value of the several field crops in Manitoba, for the period 1928 to 1937:

Crop	Acres	Value
Miscellaneous crops	13,000	$ 383,000.00
Flax	59,000	527,000.00
Fodder corn	35,000	678,000.00
Potatoes	34,000	1,592,000.00
Hay crops	463,000	5,189,000.00
Mixed grain	18,000	121,000.00
Rye	87,000	711,000.00
Barley	1,454,000	11,137,000.00
Oats	1,481,000	10,430,000.00
Wheat	2,575,000	25,404,000.00
TOTAL	6,219,000	$56,172,000.00

Wheat, of course, is the crop most extensively grown and it is also the one of greatest total value. During the ten-year period referred to above, it occupied slightly over 41 per cent. of the area under field crops, and amounted to 45 per cent. of the total value of these crops.

Disease Losses Greatest in Cereals. Owing to the importance of cereal crops in this province, it is obvious that diseases that seriously affect them are of great economic importance. In this discussion, therefore, attention is given largely to diseases of cereals, for it is through them that the greatest losses are caused. Diseases of the other field crops occur to a greater or less extent, but, the loss due to them, for the province as a whole, is comparatively small, although one disease or another may cause serious loss to growers of some particular crop or crops.

Loss in Yield Defined. Accurate estimates of losses due to plant diseases are very difficult to arrive at. From season to season, the yield per acre of any crop varies greatly owing to differences in weather conditions and in disease intensities. The actual yield represents what a crop produces in spite of disease attack or unfavourable weather conditions. Not infrequently it happens that certain plant diseases, in fact many of them, are more destructive in good-growing seasons than in less favourable ones. Consequently, the average annual yield over a period of years tends to be very much less than it otherwise would be if the crops had only to contend with weather conditions.

Obviously, then, in estimating the loss due to some particular disease in any year, the difference between the average annual yield and the actual yield in that year cannot be taken as the amount lost, for, if the disease had been absent, the yield would probably have been greatly in excess of the annual average. The loss in yield from any diseases is, in fact, represented by the difference between what the crop would have yielded in the absence of the disease and what it did yield with the disease present. In other words, the loss is the difference between the possible, or potential, yield and the actual yield.

In this report some observations are made regarding the more common diseases of field crops in Manitoba and recommendations are given for their control. Estimates are presented of the losses caused by some of the more important diseases of cereals. No estimate of loss due to any of the other field crop diseases has been attempted, for the reason that some of these diseases are relatively unimportant, and information regarding the prevalence and severity of others is too incomplete to provide an adequate basis for such an estimate. In those cases where estimates of losses are made, the actual yield data used in the calculations were taken largely from the Crop Bulletins issued by the Manitoba Department of Agriculture.

DISEASES OF NON-CEREAL CROPS

BEAN DISEASES

BACTERIAL BLIGHT

Bacterial Blight[1] attacks the leaves, stems and pods of the plants. On the leaves, the infected spots first appear water-soaked, later becoming brown and brittle; on the stem, they are reddish-brown; and on the pods, sunken and brick red. On the seed, they are yellowish. The seed becomes infected sometimes from pod infections that penetrate through to the seed, and sometimes by the migration of bacteria up the water-conducting tubes of the plants into the seed. Owing to this migration of bacteria the seed within the pods may become infected yet no infection may be visible on the pods themselves. For this reason the selection of clean pods as a source of seed is no guarantee that the seed is actually free from infection. As the bacteria may be within, as well as on, the seed, seed disinfection is only of partial value as a means of control. Only seed without discolorations or blemishes should be sown. Cultivating operations should be carried out when the plants are dry, for, in the course of these operations, the bacteria are readily spread from diseased to healthy plants when the plants are wet.

ANTHRACNOSE

Anthracnose[2] causes cankers on the stems, and sometimes infections occur on the leaf veins. Infected pods (Fig. 1), show sunken dark-coloured spots, which produce for a while flesh-coloured masses of spores. On the seed the spots vary in colour from brown to black. The seed becomes contaminated from pod infections that penetrate through to the seed. As the fungus responsible for the disease may invade the interior of the seed, surface disinfection of the seed is only of partial value as a means of control. If, however, the pods are healthy the seed within them will be healthy, and, consequently, the selection of healthy pods is a safe way of obtaining healthy seed. As in bacterial blight, no seed showing discolorations or blemishes should be sown, and cultivation should be done when the plants are dry.

FIGURE 1
Bean pods showing anthracnose infections. Spores of the anthracnose fungus are produced in these spots. The fungus may penetrate through the pods and infect the bean seeds inside. (Courtesy of Dr. H. T. Gussow.)

PEA DISEASES

ROOT ROT

The pea crop is sometimes affected by root rot[3], caused by a soil-borne fungus that attacks the base of the stem and upper part of the tap root. As the fungus lives in the soil, the best way to control the disease is by practicing crop rotation and keeping the land as free as possible of plant refuse.

LEAF BLOTCH

Leaf blotch[4] occasionally occurs. It usually appears on the lower leaves and produces yellowish to brownish blotches. As far as known, leaf blotch causes relatively little loss.

(1) Pseudomonas Phaseoli E.F. Sm.
(2) Colletotrichum Lindemuthianum (Sacc. & Magn.) Bri. & Cav.
(3) Fusarium Solani (Mart.) var. Martii (App. & Wr.) Wr. f. 2 Snyder.
(4) Septoria Pisi West.

POWDERY MILDEW

Powdery mildew[1] is prevalent almost every year and probably causes considerable damage, but little information is available as to the amount. It may be carried over from one year to the next by infected seed. Spraying with Bordeaux mixture or dusting with fine sulphur, if begun about flowering time and repeated at intervals through the summer, will keep it fairly well under control.

FLAX DISEASES

WILT

The principal disease of flax in Manitoba is wilt.[2] It has been the cause of very considerable damage. The fungus responsible for it lives in the soil and attacks the underground parts of the plants. If the plants are attacked in the seedling stage they are generally killed outright. If attacked later, some may die while others struggle along in an unthrifty condition. Within recent years varieties resistant to wilt have been made available and two of them, Bison and Redwing, are recommended for use in this province. The general cultivation of these two varieties will largely reduce losses from this disease.

RUST

Flax rust,[3] on the other hand, attacks the above-ground parts of the plants. Infection can occur at any stage so long as the plants are green. In early summer the leaves and stems show bright orange round pustules. Later on the black stage appears, when black to purplish smooth crust-like spots are present on the stems. Fortunately the variety Bison is resistant, and the variety Redwing moderately resistant to flax rust. By the use of these varieties damage from rust as well as from wilt should be largely eliminated.

HEAT CANKER

Occasionally heat canker causes some injury. Girdling of the stem occurs at ground level, owing to high temperature of the soil surface. Thickly-sown fields are usually less affected than thinly-sown ones. Early seeding helps to prevent it.

CORN DISEASES

RUST

Corn rust[4] is very frequently present on this crop, but it is seldom, if ever, severe. In occasional years a fairly liberal sprinkling of pustules occurs on the corn leaves and some damage must result, but how much is quite unknown.

SMUT

The chief disease of corn is smut.[5] Galls, or smut boils (Fig. 2), occur on all the above-ground parts of the plants. The disease is difficult to control, as the organisms responsible for it persist in the soil from year to year. Crop rotation should be practised. Certain varieties of corn are much more resistant than others. Wherever practicable, galls should be picked off into paper bags and burned. This helps to prevent further soil infestation.

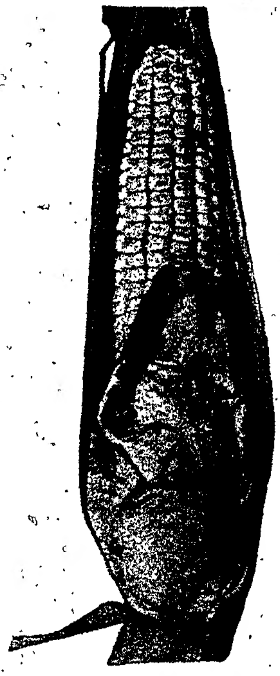

FIGURE 2
A corn cob, with part of husk removed, showing smut boils. These boils are filled with masses of smut spores. The outside covering of the boils readily breaks up and the wind blows away the spores. (Courtesy of Dr. H. T. Gussow.)

The loss from corn smut in Manitoba has never actually been determined. Apparently it is considerably greater than at present generally suspected. Immer and Christensen (Phytopathology 21: 661-674. 1931) showed that large smut galls caused

(1) Erysiphe Polygoni D.C.
(2) Fusarium Lini Bolley.
(3) Melampsora Lini (Pers.) Lev.
(4) Puccinia Sorghi Schw.
(5) Ustilago Zeae (Beckm.) Unger.

greater loss than small galls. In F_1 crosses of corn, they compared the yields of oven-dried, shelled corn from plants bearing single galls and plants free from smut galls. Ears actually destroyed by smut galls, of course, were a complete loss; but, in addition to this loss, they found a reduction in the yield of shelled corn, due to galls on other parts of the plants, amounting to about 50 per cent. for large galls, 25 per cent. for medium-sized galls, and 10 per cent. for small galls, or roughly 30 per cent. for all sizes of galls. From their results it would appear that if 50 per cent. of the plants were infected with smut, a single gall on each plant, there would be a loss in yield of shelled corn of approximately 15 per cent.

Whether or not the loss would be equally as great in an ordinary commercial variety of fodder corn is not known, but it seems that losses from corn smut have been generally very much under-estimated. As far as fodder corn is concerned, there is an additional loss: smutted plants tend to be less vigorous in growth and to produce fewer tillers than smut-free plants, so that there must be a considerable loss in the quantity of fodder produced by a smutted crop.

POTATO DISEASES

Many different diseases affect potatoes, but fortunately not all of them are prevalent in Manitoba. Late blight, the most destructive one, was unknown in this province until 1927, a wet year. In 1928, another wet year, it caused some damage in the Red River Valley. It has not appeared since, but may appear again during some damp season. Wart, a serious disease in Europe, has so far been successfully excluded from Canada

FIGURE 3
A potato vine showing symptoms of wilt caused by one of the potato-wilt fungi (Verticillium albo-atrum). (From Report of the Dominion Botanist for 1921.)

The chief diseases, in descending order of importance, in Manitoba during the last few years are (1) wilt, (2) black scurf, or Rhizoctonia, (3) black-leg, (4) mosaic, and (5) leaf roll. Spindle tuber was rather common in 1937. Early blight and tip burn are frequently present, but usually are of minor importance. To what extent such diseases actually reduce the yield of the potato crop in Manitoba has never been computed, but the average annual loss from all diseases is perhaps as much as 10 per cent.

WILT

Wilt may be caused by two different fungi, and hence should be more properly referred to as wilts. One is known as Fusarium wilt,[1] the other (Fig. 3) as Verticillium wilt.[2] The fungus responsible for Fusarium wilt also causes a storage dry-rot. Both wilts are very similar in appearance and hence difficult to distinguish in the field. They are generally more prevalent on plants grown in light soils. As the fungi responsible for them live in the soil, they are somewhat difficult to control. Infected tubers when planted produce infected plants. Comparative freedom from wilts can be obtained by good cultural practices. Rotation of crops is essential. All wilt-affected plants should be dug up, and both vines and tubers destroyed. Only sound tubers should be used for seed, and any seed showing internal browning should be discarded. The use of certified seed is strongly recommended.

(1) Fusarium oxysporum Schlecht
(2) Verticillium albo-atrum Reinke & Berth

BLACK SCURF OR RHIZOCTONIA

Black scurf[1], often called Rhizoctonia, gets its name from the black fungous bodies (sclerotia) resembling particles of soil present on infected tubers. The fungus causing this disease attacks many other crops, and is present practically everywhere in the soil. Some investigators claim that treating tubers with a disinfectant, such as mercuric chloride, before they are cut for seed is beneficial. Others consider such treatment as of doubtful value owing to the prevalence of the fungus in field soils. Tubers as free from sclerotia as possible should be used for seed. A long rotation of crops is of value. Early digging is to be recommended.

BLACK-LEG

Black-leg[2] is a bacterial disease, and is carried over from one year to the next by infected tubers. When an infected tuber is cut, some of the bacteria adhere to the knife blade, so that healthy tubers cut by the same knife become contaminated. The disease is relatively easy to control. Disease-free seed produces a healthy crop, consequently such seed should be planted. Certified seed is practically free from the disease, but may become contaminated by knives already used to cut diseased tubers. It is advisable before cutting tubers to treat them with a disinfectant, such as mercuric chloride. The knife should always be disinfected after cutting a decayed tuber before another tuber is cut. Decayed tubers, of course, should be discarded and later destroyed.

BACTERIAL WILT AND ROT[3]

In 1938, bacterial wilt and rot, a comparatively new disease in Canada, occurred at one point in Manitoba. This disease is usually regarded as a serious one. It only becomes evident in the field late in the season, when it causes a wilting and yellowing of the leaflets and finally the death of the leaves. In an infected hill, some of the stems may wilt while others appear healthy. The disease causes a tuber rot. Some of the tubers in a diseased hill may be badly decayed, while others are only moderately or slightly decayed. Some may appear sound. The infection starts at the stem end of the tuber, and causes a creamy, yellow, or light brown crumbly, or cheesy rot, which has no odour. (Other bacteria may enter diseased tubers later and produce soft rots). Some severely diseased tubers may have cracks or reddish discolorations on the skin.

The bacteria overwinters in and on the tubers. Sound or apparently sound tubers may, therefore, carry the bacteria. At planting time, knives and planters become contaminated and spread the bacteria to healthy sets. It is not definitely known yet whether or not the bacteria can survive the winter in field soil. It is inadvisable, however, to plant potatoes again in land that produced a diseased crop the previous year. The most important means of controlling this disease is by the use of clean seed. Certified seed potatoes are the only ones that can be recommended for planting.

Whenever the disease occurs, it is advisable to sterilize thoroughly all equipment that has been used in connection with the crop. Warehouses and cellars should be sprayed with a solution containing one pound of bluestone in ten gallons of water, and bags, tools, machines, etc., should be disinfected with a solution containing one pint of formalin in thirty gallons of water.

VIRUS DISEASES

Mosaic, leaf roll, and spindle tuber are caused by plant viruses. Each of these diseases is transmitted through the seed (tubers). No known seed treatment is of any value. It is, therefore, absolutely essential to plant healthy seed. In the field, infected plants (including tubers) should be rogued out as soon as noticed, and destroyed. Certified seed should be purchased if there is any doubt about the health of the home-grown stock.

DISEASES OF HAY CROPS

Under hay crops are included such crops as brome, timothy, western rye (slender wheat) grass, alfalfa, sweet clover and common clover. Several different diseases affect each of these

(1) Rhizoctonia Solani Kuhn.
(2) Erwinia atroseptica (van Hall) Bergey et al.
(3) Bacterium not yet definitely determined.

crops, but, in general, none of them cause very pronounced damage. This, at any rate, appears to be the situation; but as yet in this province very little attention has been given to diseases of these crops, and a careful survey of them might show that the amount of injury from disease is much greater than at present suspected.

DISEASES OF CEREAL CROPS

Mention has already been made of the fact that 90 per cent. of the land under crop in Manitoba is devoted to the growing of cereals, and that diseases that seriously affect these crops assume a great deal of importance in the economic life of the province. In addition to the more serious diseases, several minor diseases of each of the principal cereal crops occur, and in certain seasons cause appreciable loss. Besides these, there are a number of others that are relatively unimportant, and, consequently, need not be referred to here. There is no guarantee, however, that these will always remain unimportant, but, for some years, at least, they have not been of much consequence in this province.

MINOR CEREAL DISEASES

BACTERIAL BLACK CHAFF

Bacterial black chaff[1] occurs on wheat. It was quite prevalent in 1928 and again in 1935, but in the latter year the injury caused by it was masked by the severe damage from stem rust. It causes a dark discoloration of the heads (Fig. 4) and sometimes of portions of the stem. The disease is seed-borne, and contaminated seed can be disinfected by the hot water treatment. Seed treatment with organic mercury dusts, such as used for the control of bunt of wheat, is helpful. Some varieties of wheat are much more resistant to it than are other varieties.

FIGURE 4
A head of wheat showing symptoms of bacterial black chaff. Notice the discoloration is chiefly towards the tips rather than at the bases of the glumes. (Photograph by Dr W. A. F. Hagborg.)

FALSE BLACK CHAFF

Here it may be mentioned that a dark discoloration of the glumes (Fig. 5) and occasionally of portions of the stems, usually near the joints, is sometimes present on certain of the new rust-resistant wheat varieties, such as Apex and Renown. The discoloration is commonly referred to as "black chaff," but it may be present when the bacterial black chaff organism is absent, and, consequently, the name black chaff is misleading. At present the cause of the discoloration is not completely understood, but it seems to be a response on the part of these wheat varieties to fungous or bacterial infection which, in most cases, seems to do little or no damage. Sometimes, however, the discoloration is accompanied by a greater or less amount of spikelet sterility. Environmental conditions appear also to play some part, but the relation is not yet altogether clear.

FIGURE 5
A head of wheat badly injured by false black chaff. Notice the dark discoloration of the chaff and the spikelet sterility towards the tip. (Photograph by Dr W. A. F. Hagborg.)

HALO BLIGHT

Halo blight[2] of oats, a bacterial disease, is common almost every year. It occurs chiefly on the leaves, but sometimes on the leaf sheaths and glumes. Spots or blotches with dead centres and yellowish-green margins, which give the appearance of a halo around the dead centres, are characteristic

(1) *Pseudomonas translucens* J. J. & R. var. *undulosa* (Sm. J. & R.) Stev.
(2) *Pseudomonas coronafaciens* (Ch. Elliott) Stev.

of the disease. When infection is severe, the blotches may involve the whole leaf surface, and cause the leaves to turn brown and die. Undoubtedly this disease is responsible for considerable damage, for, by injuring the green leaves, it prevents them from manufacturing the normal amount of food, and hence the kernels are robbed of an adequate food supply. The likelihood is that it causes more damage than it is usually thought to do. Seed treatment with organic mercury dusts is beneficial, but does not entirely control the disease.

OAT BLAST

Blast of oats is a non-parasitic disease. Spikelets, most frequently those towards the base of the panicle, are undeveloped (Fig. 6). In blasted spikelets, kernels are absent, and the glumes, or chaff, may be fairly well developed, but all gradations in glume development are met with from normal-appearing ones to ones so poorly developed as to be all but missing. It should be made clear that the blasted spikelets are not destroyed after they are formed; they cease development at one stage or another before completing their normal process of growth. This diseased condition is very common in oats. In many varieties of oats there seems to be a hereditary tendency to under-development of some of the spikelets in the panicle. This tendency is intensified by various factors operating while the panicle is in its early stages of development; exposure to drought conditions, severe leaf injury, damage from root rot, and nutrient deficiency, especially of nitrogen, all tend to increase the amount of blast. By way of control, about all that can be done is to provide the plants with as favourable growing conditions as possible.

FIGURE 6
A panicle of oats showing blasted spikelets. Notice the thin papery appearance of the affected spikelets. (Photograph by Mr. A. M. Brown.)

ERGOT

Ergot[1] attacks rye, barley, wheat, sometimes oats, and many different grasses, such as brome, timothy, blue grass, quack grass, etc. In the heads of diseased grains and grasses, hard horn-like fungous growths, called sclerotia, take the place of the true kernels (Fig. 7). These sclerotia, or ergot bodies, are quite highly poisonous. The importance of the disease in Manitoba does not lie so much in the actual damage it does to a crop as in the danger of poisoning to man and stock. Care should be taken to remove any ergot bodies that may be present in grain that is to be used for human consumption as well as from grain that is to be fed to stock. Hay that is heavily contaminated with ergot should not be used for feed.

The chief source of infection in Manitoba appears to be infected grasses growing along headlands and roadsides. These should be cut soon after they come into head. As the ergot bodies begin to develop shortly after the plants come into flower, the early cutting of the grass prevents their formation. Grain or grass seed containing ergot bodies should be thoroughly

(1) Claviceps purpurea (Fr.) Tul.

cleaned before being sown. Most of these bodies can be removed by cleaning machines, but small or broken ones are difficult to get rid of. The most effective way of eliminating them is to immerse the seed in a strong brine, made by adding 40 pounds of common salt to 25 gallons of water. The seed is then stirred, and the ergot bodies float to the surface where they can be skimmed off. To prevent injury to germination, the seed must then be thoroughly washed to free it of salt, and dried immediately afterwards.

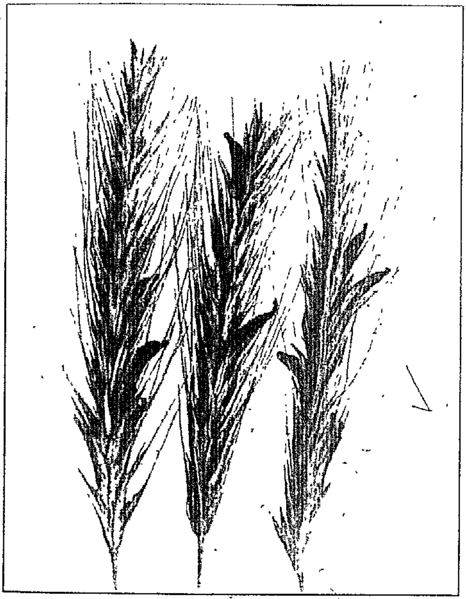

FIGURE 7
Heads of rye showing heavy infection of ergot. Notice that the ergot bodies are produced where healthy kernels should be. (Photograph by Mr. A. M. Brown.)

BARLEY STRIPE

Barley stripe[1], as the name implies, produces long stripes, brownish in colour, on the leaves and leaf sheaths and is often accompanied by shredding of the affected plant parts. Diseased plants are often stunted, and frequently the heads fail to emerge from the boot. Although infected plants usually produce no seed, yet spores from such plants infect the kernels of healthy plants. The disease is, therefore, seed-borne. Seed from disease-free fields should be sown; but if such seed is not available, the seed should be treated with organic-mercury dusts, such as are used for the control of bunt in wheat.

MAJOR CEREAL DISEASES

The more important diseases of cereals in Manitoba can be grouped into three classes, (1) root rots, (2) smuts, and (3) rusts. The chief crops affected by these are wheat, oats and barley. Rye is a relatively unimportant crop in this province, and, as it is usually comparatively free from serious disease injury, except root rot, it need not occupy much space in this discussion. Passing reference, however, may be made to a few of the diseases that affect it.

The most conspicuous one is ergot, a disease to which rye is particularly susceptible. Traces of it occur in practically every field of rye, but, as a rule, it is not generally severe enough to cause much loss. Stem rust[2] rarely occurs on rye. Leaf rust[3] of rye is often present, but it is never very destructive. Stem smut[4] of rye occasionally occurs, but seldom is it common enough to cause appreciable damage. Usually only chance stems are affected. Root rot[5] is more or less common in rye, and some fields have been observed in which considerable injury was evident.

(1) *Helminthosporium gramineum* Rabh.
(2) *Puccinia graminis* Pers. var. *Secalis* Erikss. & Henn.
(3) *Puccinia secalina* Grove
(4) *Urocystis occulta* (Wallr.) Rabh.
(5) *Helminthosporium* and *Fusarium* species.

The other cereal crops, wheat, oats and barley, are grown much more extensively than rye, and it is in these that most of the damage occurs. Some observations concerning the more common diseases and methods of controlling them, together with estimates of the damage caused by some of them, are given below.

ROOT ROTS

Root rots of cereals are caused by soil-inhabiting fungi. The injury caused by some of these fungi is not, however, confined to the roots and crowns of the plants. Spores from the soil or from diseased plant parts are blown about by the wind and come in contact with the above-ground parts of the plants, and infect them. Certain of these fungi cause leaf spots on the different crops, and two of them are largely responsible for kernel smudge, or "black point." The greatest loss, however, from these fungi usually occurs through damage to the underground parts of the plants.

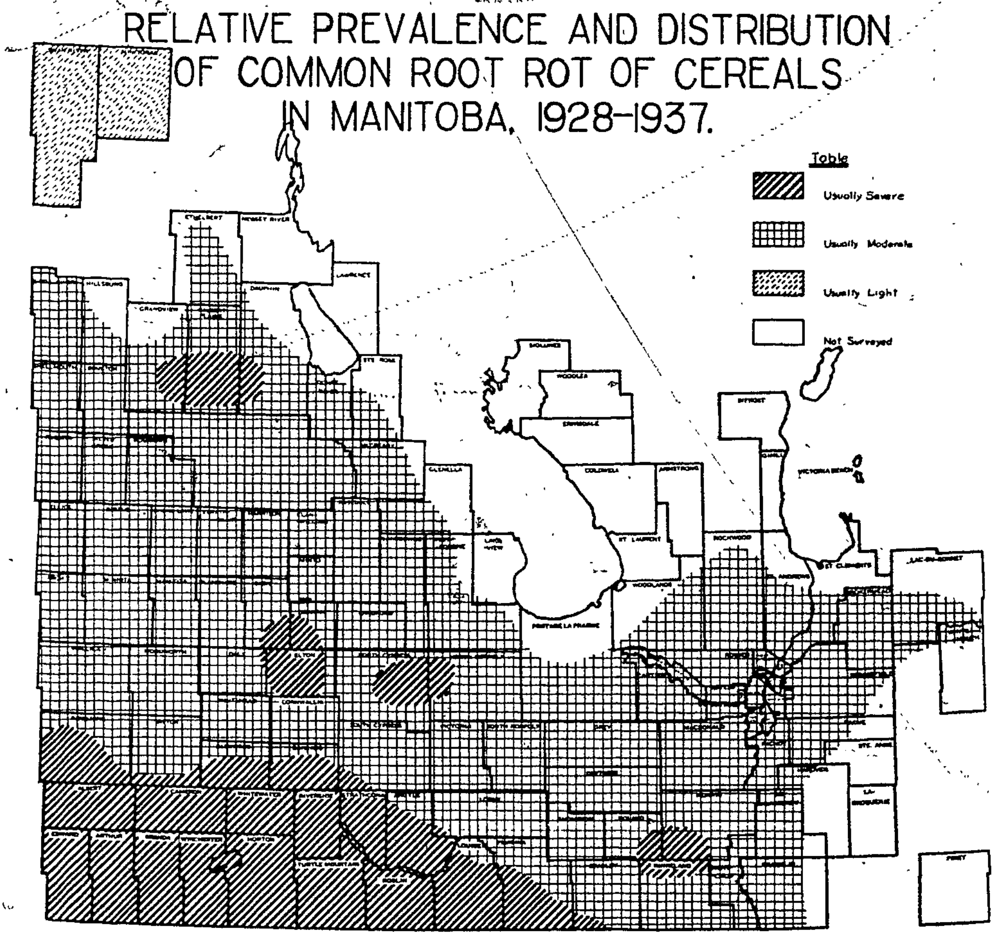

FIGURE 8

Relative prevalence and distribution of common root rot of cereals in Manitoba during the ten year period 1928-1937.

Occurrence and Distribution. The most wide-spread and important of these diseases in Manitoba is common root rot. It is present every year and in all the grain-growing parts of the province, and affects all cereal crops. As a rule, it is most prevalent in the southern part of the second prairie steppe and in several smaller areas (Fig. 8). Take-all[1] is seldom present, although in 1935 it was fairly common on wheat in the Swan River Valley. It has not been found attacking oats in this province (or, in fact, in either of the other two prairie provinces). Another root rot, called browning, was first observed in Manitoba in 1933. In 1937 it was common in the Brandon-Minnedosa and severe in the Dauphin-Gilbert Plains area.

Influence of Weather and Soil Conditions. Because of the fact that the organisms responsible for these diseases live in the soil, they are influenced to a considerable extent by climatic and soil conditions, as well as by cultural practices. For example, common root rot usually does most damage in seasons in which rains are frequent in the early summer and dry hot weather follows in late summer, particularly if sub-soil moisture from the previous season is scanty. In such seasons crop growth is heavy, and even plants with a healthy root system suffer from lack of water; while those with diseased roots are much less able to survive, and many of them dry up and die before they are mature. Furthermore, this disease is particularly prevalent in saline, or salty, and in light soil, especially where it has drifted badly.

BROWNING

Browning[2] generally occurs in soils with a fair amount of organic matter, but with low phosphorus content. The disease is nevertheless of fungous origin. It is characterized by a browning of the leaves when the plants are about three or four weeks old. Affected plants usually recover. Owing, however, to the setback received they lack vigour and mature late, and thus, when browning is prevalent, damage from stem rust is increased, and weeds have a good opportunity to develop. This disease can be very largely prevented by the use of phosphate fertilizers.

KERNEL SMUDGE

Kernel smudge[3], frequently called "black point," causes a more or less conspicuous brownish to blackish discoloration of the seed (Fig. 9), particularly of the germ end. It occurs on wheat and barley, and is caused by fungi, principally by two, that regularly live in the soil and frequently attack the roots and basal parts of the plants. Infected seed, of course, carries the fungi, and seed containing many discoloured kernels should not be sown. Seed treatment with organic mercury dusts, such as used against bunt, controls the disease in so far as seed-borne infection is concerned, and helps to prevent seed decay in the soil and seedling blight; but, in spite of seed treatment, the disease may appear in the new crop, owing to the fact that wind-borne spores may infect the kernels either before or at the time the crop is maturing. In other words, seed treatment is of value, but the disease may appear in the new crop even although the seed has been treated. Durum wheat is particularly subject to this disease. In most years the chief loss comes through a lowering of the grade of the affected grain, but the extent of the loss has not yet been ascertained.

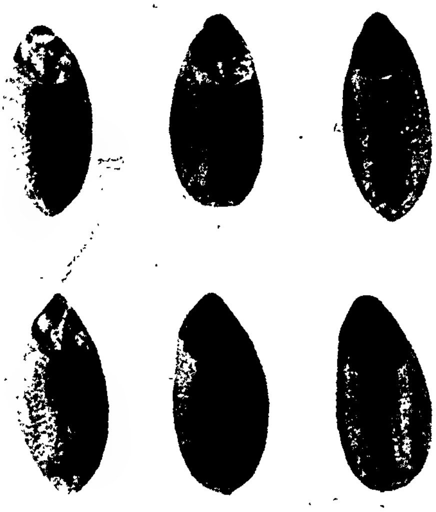

FIGURE 9
Kernels of Pentad wheat. The two on the left are healthy, the others are discoloured, or blackened, by kernel smudge. Notice the dark colour of the germ end of the smudged seed. (After Machacek and Greaney.)

(1) *Ophiobolus graminis* (Sacc.) Sacc.
(2) *Pythium arrhenomanes* Drechsler var. *canadensis* Vant. & Truscott chiefly.
(3) *Alternaria* and *Helminthosporium* species chiefly.

LEAF SPOTS

Leaf spots (Fig. 10) frequently do some damage in the northern parts of the province. In the southern parts, only sporadic outbreaks occur. They are caused largely by spores formed in the fall and spring on stubble, straw, chaff, etc., as well as on grass weeds. Plowing down such material, to bury the spores, or burning it, will help materially to reduce the amount of leaf spotting.

—FIGURE 10
Barley leaves showing leaf spots caused by a root rot fungus (Helminthosporium sativum). Notice that the tips of the leaves are drying up and dying. (After Greaney and Machacek.)

COMMON ROOT ROT

Common root rot[1] may be caused by several different fungi. It attacks both seedlings and mature plants. As a seedling blight it may kill off a large number of seedlings, and those that survive usually fail to tiller properly, so that stands of affected crops are usually thin. Diseased plants are less vigorous than healthy ones, and they produce fewer and smaller kernels. If they ripen prematurely, they may produce few or no kernels at all.

Methods of Control. As might be expected, common root rot is rather difficult to control. Summerfallowing is beneficial, and crop rotation should be practised. Fertilizers provide additional plant food, so that plants with diseased roots have a better chance of surviving in fertilized soil than they have in unfertilized soil. Where common root rot is severe in saline areas, the addition of an acid fertilizer or barnyard manure will help to reduce the damage. Seed treatment with organic mercury dusts will prevent seedling blight, an early phase of this disease. Certain varieties of wheat are known to be much more resistant than others to it, and there is the possibility of breeding wheat varieties possessing higher resistance than is possessed by the varieties that are now commonly grown.

Estimate of Damage. The actual loss due to common root rot is somewhat difficult to estimate. Durum wheat is particularly susceptible to it, and, owing to the extensive cultivation of Durum, the loss is higher than if the wheat acreage were all sown to common wheat. Oats and barley suffer as well as wheat. As judged by the results obtained in experimental plots at Winnipeg, the average annual loss in wheat, oats and barley is not less than 5 per cent. Certainly, in some years, it is very much greater, and in very few years is it less. Calculated on a basis of 5 per cent. loss in yield (Table 2), the annual cash loss to Manitoba for these three crops amounts to $2,470,000.00.

(1) Helminthosporium and Fusarium species chiefly.

Table 2—Yield and cash losses in Manitoba, based on a 5 per cent. reduction in yield, due to common root rot in the three principal cereal crops.

Crop	Average Annual Yield (1928-37) Bushels	Average Annual Loss	
		Bushels	Dollars[1]
Wheat	36,265,000	1,909,000	1,336,000.00
Oats	34,743,000	1,828,000	548,000.00
Barley	28,556,000	1,503,000	586,000.00
			2,470,000.00

Little information is available prior to 1928 regarding root rots of cereals in this province, so that the average annual yield is taken for the period 1928-37 instead of the period 1916-37. It is not known whether or not root rots were as troublesome from 1916 to 1927 as they were from 1928 to 1937, and hence the estimate does not apply to the earlier period. Owing to the low price of grain during most of the last ten years, the cash loss given here is lower than if the average prices were those for the 22 year period.

SMUTS

The smuts are caused by parasitic fungi, which generally produce dark spore masses in localized portions of the infected plants. In some smuts, such as the stem smut of rye already mentioned, the spore masses develop in the stems and leaves, forming long parallel streaks which rupture and thus liberate the spores. In the six cereal smuts discussed here the spore masses develop regularly in the heads of the plants, displacing and destroying the seed, and, in all but one of them, destroying altogether or partly the chaff also. These six smuts are very generally distributed throughout Manitoba. They are as follows: (1) bunt, or covered smut, of wheat, (2) covered smut of barley, (3) covered smut of oats, (4) loose smut of oats, (5) loose smut of wheat, and (6) loose smut of barley.

All of the smuts just named are seed-borne, but they fall into two distinct classes, according to the manner in which the organisms responsible for them are carried over from one crop season to the next. The organisms responsible for the smuts in the first class are carried on the surface of the seed, whereas those responsible for the smuts in the second class are carried within the seed.

SMUTS CARRIED ON SEED SURFACE

BUNT OF WHEAT

Two closely related fungi are responsible for bunt[2], or covered smut, of wheat. Either of them may cause the disease. The spore masses are produced within the spikelets of the heads, where the wheat kernels should develop. They are firm and compact, and are usually referred to as bunt balls. This smut does not destroy the chaff (Fig. 11), and hence bunted wheat plants are not very noticeable in the field. When, however, the grain is threshed, the bunt balls are threshed out with the grain and mixed with it. Many of the bunt balls are broken up in the threshing operation, and the spores (Fig. 12) become scattered over the surface of the sound grain. When such bunt-contaminated grain is sown, the spores germinate and infect the young wheat sprouts just as they emerge from the seeds. The fungus then keeps pace with the plants in growth, so that when the plants have headed and should be producing sound healthy kernels, the fungus prevents this development and, in their place, produces the spore masses, or bunt balls.

(1) Average price per bushel, 1928 to 1938: wheat, \$0.70; oats, \$0.30; barley, \$0.39.
(2) Tilletia laevis Kuhn and T. Tritici (Bjerk.) Wint.

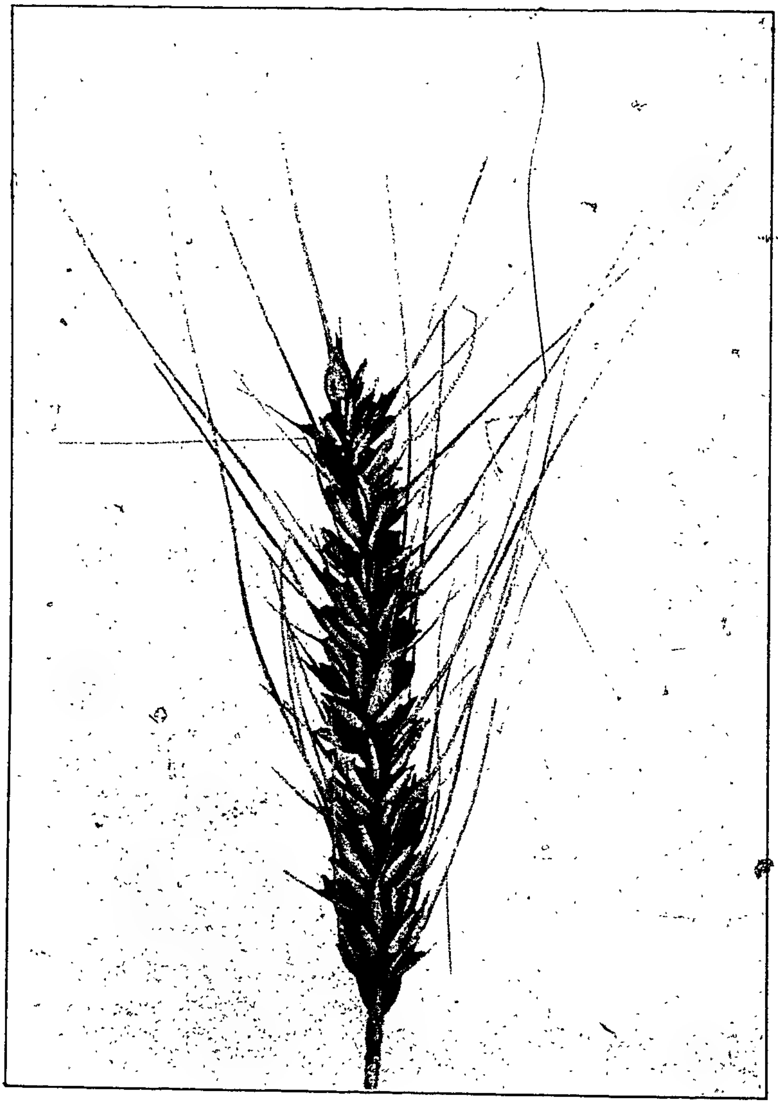

FIGURE 11
A head of wheat destroyed by bunt. The glumes have been spread apart to show the spore masses, or bunt balls, present inside the glumes. (Photograph by Dr. W. F. Hanna).

Dockage Due to Bunt. Bunt of wheat is frequently called stinking smut owing to the fact that spores of the bunt fungi usually emit an unpleasant odour, resembling that of spoiled fish. Wheat contaminated with such spores often carries this disagreeable odour, which, together with the dark colour given to the flour, makes the wheat unfit for bread-making purposes. Such wheat must be washed before it is fit to be ground into flour. To offset this extra cost, the price of bunted wheat is always somewhat lower than that of clean wheat of equal grade. In addition, therefore, to the loss in yield, there is a further loss incurred through dockage of wheat that grades "smutty." The dockage varies somewhat from year to year, but averages perhaps about ten cents per bushel.

COVERED SMUT OF BARLEY

In many respects the covered smut of barley[1] resembles bunt of wheat, although it is caused by a different fungus: spore masses displace the kernels in infected plants; the spores are dusted over the sound kernels during threshing operations; and infection of the barley sprouts takes place in the soil, the infection being caused by seed-borne spores. Unlike bunt,

(1) Ustilago Hordei (Pers.) Lagerh.

however, this smut destroys and displaces the hulls of the kernels, except the tips and awns, which remain more or less intact. The spore masses are covered with a thin white membrane through which the dark spore masses can be seen, and, in consequence, the infected heads have a dull greyish colour. The spore masses are broken up at the time the grain is threshed, so that the spores are scattered over the seed. Broken pieces of the spore masses commonly occur in the smutty grain.

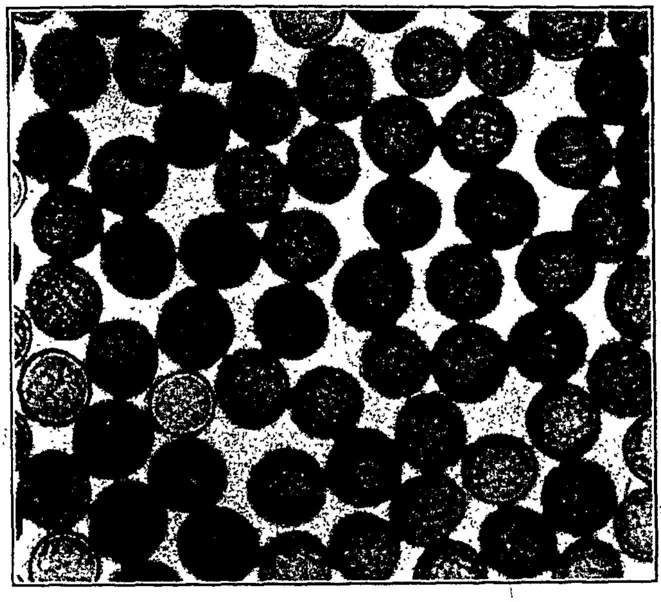

FIGURE 12
Spores of one of the fungi (Tilletia Tritici) that cause bunt of wheat. Notice the characteristic markings on the spore-wall. Magnification. 500 app. (Photomicrograph by Dr. W. F. Hanna.)

OAT SMUTS

The two smuts of oats, loose smut[1] and covered smut[2], are caused by two different fungi, but in the field it is rather difficult sometimes to distinguish one from the other. They are first noticeable when the crop begins to head. As in covered smut of barley, the young kernels of the infected plants are completely destroyed and displaced by the dark spore masses. In fact, the spore masses are formed before the kernels have an opportunity to develop. In both smuts the head, or panicle, is stunted; but, in loose smut, the branches of the head stand erect and close to the central axis, thus giving the smutted head a compact appearance, while, in covered smut, there is a tendency for the head to retain more of its normal appearance, the smutted spikelets drooping somewhat instead of standing erect as in loose smut. In loose smut the chaff is completely destroyed, whereas in covered smut it is only partly destroyed.

As the loose smut spores are exposed directly to the wind, the bulk of them are dispersed early in the season, in fact, at the time when the crop is in flower. Some of them come into contact with the developing seed and contaminate it. The spore masses of covered smut, being better protected than those of loose smut, remain more or less intact until the crop ripens. The spores are scattered over the grain at the time the grain is threshed. When oats, contaminated with either smut are sown, infection of the young sprouts occur. In each case the fungi keep pace in growth with the plants, so that, when the crop comes into head, the infected plants produce smutty heads, rather than healthy ones. Year after year this cycle of development takes place.

METHODS OF CONTROL

As these four smuts are carried over from season to season on the seed, they all can be controlled by disinfecting the seed with a suitable fungicide. In wheat seed contaminated with bunt there are usually unbroken or partly broken bunt balls present. Spores in them are very well protected and may not be killed by the fungicide used for treating the seed. For this reason it is necessary to run the seed through a good cleaning mill to remove the bunt balls before the seed is treated with the fungicide. If the bunt balls are not removed, they may be broken up while passing through the drill, or in some other way, and hence recontaminate the treated grain. The same difficulty may be encountered with smutty

(1) Ustilago Avenae (Pers.) Jens.
(2) Ustilago levis (K. & S.) Magn.

barley seed if the spore masses are not removed before the seed is treated. In the oat smuts this difficulty is not met with, as unbroken spore masses are rarely present among the seed.

The fungicides used in recent years for the control of these diseases are the organic mercury dusts, formaldehyde, and copper sulphate ("blue stone") solution. Copper carbonate dust has been widely used for the control of bunt, but it does not give satisfactory control of the other three smuts. Blue stone solution causes rather severe seed injury and is no longer much used. Formaldehyde, too, causes considerable seed injury. Seedlings arising from seed treated with formaldehyde usually suffer more from seedling blight than do seedlings from untreated seed. The organic mercury dusts are very effective against these smuts. They have the advantage, too, that they give seedlings protection against seedling blight, and can be applied to the seed months before it is needed for sowing, without any danger of recontamination.

Attention must be called to the fact that the organic mercury dusts are highly poisonous and, for that reason, care must be taken, when treating grain, to avoid inhaling them. A suitable face mask may be used for this purpose. Treated grain must not be fed to stock.

Seed treatments are only temporary measures and must be repeated each year. If varieties resistant to these smuts could be grown, the necessity of seed treatment would be removed. Probably, in due course, resistant varieties suitable for Manitoba conditions will be made available through the efforts of the plant breeders. It may be mentioned, however, that the production of highly resistant varieties is made more difficult by the fact that these smuts comprise different races, which differ widely in their ability to attack the various varieties of wheat, oats or barley, as the case may be. The presence of these races, however, does not make these smuts more difficult to control by seed treatment.

SMUTS CARRIED WITHIN THE SEED

LOOSE SMUT OF WHEAT

Loose smut of wheat[1] is most readily noticed in the field shortly after the crop comes into head. The spikelets of the heads are completely destroyed and their place is occupied by dark dusty masses of smut spores. After exposure to the weather for several days most of the spores are blown away, leaving the upper end of the stem more or less free of spores and rather inconspicuous.

The spores are distributed most abundantly just when the healthy plants are in flower. Some of the spores come into contact with the very young kernels and infect them. The fungus grows for a short time inside the kernels and then becomes dormant. It does not, however, interfere with the development of the kernels, for infected kernels cannot be distinguished from healthy ones. When infected kernels germinate, the fungus breaks its dormancy and grows as fast as the plants grow. The fungus reaches the heads and destroys the young florets, and, in their place, produces the dark spore masses, the spores of which, in turn, are blown away and infect the new crop.

LOOSE SMUT OF BARLEY

The loose smut of barley[2] resembles very much the loose smut of wheat, but they are caused by two different fungi. The fungus responsible for loose smut of barley cannot infect wheat, and the one responsible for loose smut of wheat cannot infect barley. Loose smut of barley completely destroys the grain (Fig. 13). The spore masses are at first covered by a fine membrane, but it soon disintegrates, allowing the dusty spore masses to be blown away by the wind. This happens just when the healthy plants are in flower, so that infection of the very young kernels results. As in loose smut of wheat, the fungus soon becomes dormant and remains so until the seed is sown and begins to germinate. The fungus keeps pace in

(1) **Ustilago Tritici** (Pers.) Rostr.
(2) **Ustilago nuda** (Jens.) Rostr.

growth with the infected plants, and destroys the young spikelets before the heads emerge from their sheaths. When they emerge, the spores are scattered about by winds and infection occurs once again.

Here it may be mentioned that there is another fungus[1] that causes a loose smut of barley, but the spores of this fungus are carried on the seed, and infection occurs when the seed germinates. In its manner of infection, this smut resembles covered smut of barley, but, in its effect on the plant, it resembles loose smut. It has been found in Manitoba but it is apparently uncommon.

METHODS OF CONTROL

As the organisms responsible for the loose smut of wheat and of barley are carried within the seed, not on its surface, disinfection of the seed with fungicides is of little or no use as a means of control for these two smuts. The hot water treatment, however, is effective against them. Comparative freedom from both can be secured by keeping a segregated seed plot, and removing and burning smutted heads just as soon as they appear in it, to prevent the spores from infecting the rest of the plot. Such a plot of wheat, and one of barley, should be maintained year after year, and the seed from each of them used as foundation stock.

The hot water treatment has not been generally adopted as a control for the loose smuts, so that the introduction of resistant varieties would be welcomed. Here it may be mentioned

FIGURE 13

Barley plants affected by loose smut. Two of the heads are healthy, the rest are smutted. The plants were grown indoors and hence the wind did not have a chance to blow the spores away. (Photograph by Dr. W. F. Hanna.)

(1) Ustilago medians Biedenkopf.

that the presence of different races of these smuts, just as in the other group of smuts, makes the production of highly resistant varieties, that is to say, varieties highly resistant to all races, a more difficult undertaking. This matter will be referred to again later.

ESTIMATE OF DAMAGE

The cereal smuts are among the most easily controlled of all plant diseases. The use of seed treatments, especially for those smuts that are carried on the surface of the seed, has reduced very considerably the losses from these diseases, but there is still a rather heavy, although entirely needless, loss through them. Too frequently fields of oats or of barley are observed in which the loss from smut, by actual count, ranges from 10 to 20 per cent. and, occasionally, as high as 30 per cent. Considerably more care seems to be taken to treat wheat for bunt control. No general effort has yet been made in this province to control the loose smut of wheat or the loose smut of barley. Marquis wheat, which formed the bulk of the wheat crop for many years, is only moderately susceptible to loose smut of wheat, and hence the loss from this smut has been less than it otherwise might have been. An estimate of the annual reduction in yield and of the annual cash loss due to the six cereal smuts just discussed is given in Table 3. Included in this table is the annual cash loss estimated for dockage. According to these estimates, the average annual cash loss to this province through these smuts amounts to about $1,390,000.00.

Table 3—Estimated average annual loss caused by cereal smuts in Manitoba.

Crop	Average Annual Yield (1916-37) Bushels		Average Annual Loss Per Cent.	Bushels	Dollars[1]
Wheat	39,180,000	Loose smut	½	197,000	203,000.00
		Bunt	¼	98,000	101,000.00
Oats	47,432,000	Loose and covered smut	3	1,466,000	601,060.00
Barley	29,680,000	Loose and covered smut	3	916,000	416,000.00
		Dockage due to bunt			64,000.00
Total estimated average annual cash loss					1,390,000.00

RUSTS

Before the opening of the Christian era, "rust" was known as a destructive disease of cereals. It was believed to be caused by the weather, or to be an expression of displeasure on the part of some god that had been offended. The disease-producing nature of the rust fungi was not generally recognized until about the middle of the last century, although "rust" was regarded as a diseased condition of the plant before that time. It was believed that the diseased condition produced the fungi rather than that the fungi produced the diseased condition. Since that time, especially during the last quarter of a century, a great deal of study has been given to the rusts, and much has been discovered concerning their nature and parasitic capabilities.

Moisture Necessary for Development. The belief that rusts were caused by weather conditions arose from repeated observations that severe outbreaks of "rust" commonly followed periods of damp weather. There is no doubt at all that weather conditions influence rust development to a considerable extent, but it is now everywhere recognized that unless rust spores are present to infect the plants, no rust will develop. Rust spores do not germinate while they are dry and, unless they germinate, no infection can occur. The spores readily germinate when in contact with moisture. Germination of the spores, therefore, depends on the presence of moisture, a fact which, in years gone by, made it appear that the moisture caused rust.

(1) Average price per bushel, 1916-37: Wheat, $1.03; Oats, $0.41; Barley, $0.45.

On germination, each spore produces a root-like process, called a germ-tube (Fig. 14). It is the germ-tubes that enter the plants, thereby causing infections. Moisture must, therefore, remain long enough on the plants to permit the spores to germinate and also to allow the germ-tubes to gain entrance into the plants. Entrance occurs through the breathing pores (stomata) of the plants. If the moisture dries too quickly, that is to say, before the germ-tubes can enter the breathing pores, the germ-tubes wither and no infection occurs. Rust outbreaks are, therefore, usually associated with periods of moist weather or of heavy dews at night. When once the tip of a germ-tube is safely inside the breathing pore, it can then draw on the water supply of the plant, and is no longer dependent on outside moisture.

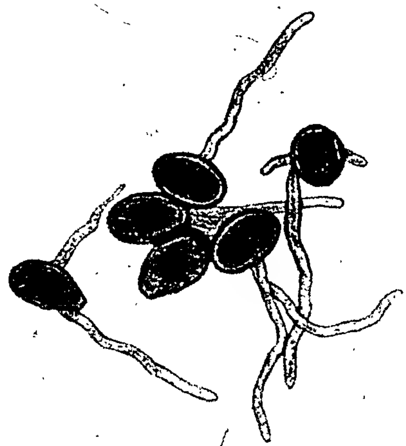

FIGURE 14
Germinating red spores, or urediospores, of the stem-rust fungus. The germ tubes enter the cereal plants through openings in the stem and leaves, called breathing pores, or stomata. Magnification, 300 app. (Photomicrograph by Mr. A. M. Brown.)

Growth Within Plant. Within the plant, the germ-tube finds a constant supply of food, as well as of water. It proceeds to grow rapidly, forming many branches, and within a few days develops into a considerable mass of fungous threads. These penetrate in all directions, running between the cells of the plant but not through them. The threads, however, produce specialized branches which enter the plant cells and absorb food and water from them, thus robbing the plant of these essentials. Within about a week after an infection occurs, the mass of fungous threads give rise to a crop of spores.

Distribution and Control. The rusts are wind-borne diseases spread by spores. The spores can only infect green plants. Infection occurs while the plants are growing in the field. As the rusts are not carried in or on the seed, or in the soil, disinfection of the seed or of the soil to prevent rust infection is of no use. Any artificial protection used against rusts must, therefore, be applied to the standing grain. Applications of sulphur dust to the growing plants, if begun before infection occurs and repeated at intervals until the plants are near maturity, will largely prevent infection in the treated plants. Cereals, however, are grown on such an enormous scale and rust spores are distributed over such a vast area that this method of rust prevention, although practical for smaller areas, would seem impracticable for the whole of the grain-growing area of the province. Broadly speaking, the only method of rust control that holds much chance of success is the production of varieties that are rust resistant.

Rusts Present in Manitoba. Six different cereal rusts occur in western Canada and all except one, namely, stripe rust[1], occur in Manitoba. Stripe rust is present almost every year in British Columbia and Alberta, although it usually develops too late in the season to do any particular damage. In occasional years, traces of it occur in western Saskatchewan. Apparently weather conditions in Manitoba and eastern Saskatchewan are too hot during the summer to permit its development.

Two of the other rusts, namely, leaf rust of barley[2] and leaf rust of rye[3], are rarely of any consequence. The latter, however, is usually more common than the former. The other three rusts are definitely of economic importance, although unequally so, in this province. They are stem rust[4], leaf rust of wheat[5], and crown rust of oats[6].

(1) *Puccinia glumarum* (Schmidt) Erikss. & Henn.
(2) *Puccinia anomala* Rostr.
(3) *Puccinia secalina* Grove.
(4) *Puccinia graminis* Pers.
(5) *Puccinia triticina* Erikss.
(6) *Puccinia coronata* Corda.

Different Rust Stages. On cereal plants, all of these rusts appear in two different guises, or stages, namely, the red stage and the black stage. Each stage is named according to the colour of the spores produced by it. All of these rusts (except stripe rust, for which none is known) have a third stage, but this stage does not occur on cereals or grasses. It occurs on some other particular kind of plant, but the kind of plant is different for each rust. These three stages make up what is known as the life cycle of a rust. The main points in the life cycles of the different rusts are similar, and, consequently, need only be discussed for one of them. This will be done presently for stem rust.

STEM RUST

OCCURRENCE IN MANITOBA

Stem rust is known to have occurred in Manitoba as early as 1891, and the likelihood is that it was present for a number of years previously. It caused considerable damage in 1896, but not until 1904 was it severe and general enough to cause any great alarm. It was fairly prevalent in 1911, particularly in the western part of the province. A very heavy attack broke out in 1916, and, subsequently, five more occurred, namely, in 1923, 1927, 1930, 1935 and 1938. Outbreaks only somewhat less severe overtook the crop in 1919, 1921, 1925 and 1937. In the remaining years of the present century stem rust was less prevalent, but, in most of them, it caused appreciable damage, particularly to late crops.

Any discussion of the origin of stem rust in Manitoba must include some reference to the third stage of the disease. Consequently, before dealing with the origin of the disease in this province, it may be well to give a brief outline of the life cycle of the fungus responsible for it in order to show the relationship between the three stages.

LIFE CYCLE

Mention has already been made of the fact that each of the cereal rusts (except stripe rust) passes through three stages, the red and the black stages on cereal or grass plants, and the third stage on some other host not belonging to the grass family. The red stage of stem rust is the only one found on cereal crops while the plants are green. It gets its name from the spores (Fig. 15) which in mass are red in colour. This is the stage in which the disease spreads so rapidly in the crops. So long as the crops remain green, this stage continues to multiply, but, when the crops begin to ripen, it gives place to the black stage. That is to say, the infections produce black spores instead of red spores. For a while both red and black spores may be present in the same pustules, but, by the time the grain is ready to cut, most of the red spores have been blown away, and only the black spores are left, the so-called "black rust."

Relation to Barberry. Owing to the fact that the black spores (Fig. 16) cannot infect cereal crops, the black stage of the disease has no further importance, unless barberry bushes (Fig. 17) are growing somewhere in the neighbourhood of the rusted grain. Indeed, the black spores do nothing further in the season in which they are formed. They remain alive, however, during the winter, and, in the spring, when the weather is warm and moist, they germinate. On germination they produce tiny colourless spores, which infect barberry, if it is growing nearby. Infections occur on the leaves and young twigs and give rise to the third stage, often called the "cluster-cup," or spring, stage of the disease (Fig. 18).

In the cluster-cups a new type of spore is produced. These spores develop in parallel chains in the cups. They are shot out singly from the cups and are carried away by wind, and, if they lodge on green cereal plants, they infect them whenever moisture is present. Infections by these spores give rise to the red stage of the disease.

In the absence of barberry the third stage cannot occur, and hence, under that circumstance, the black spores are of no use in perpetuating the disease.

The life cycle of stem rust, as briefly sketched here, is illustrated in Figure 19. It shows the three stages of stem rust and the order in which these stages occur.

Here it may be mentioned that the Japanese barberry, commonly used as an ornamental shrub, is immune from stem rust infection.

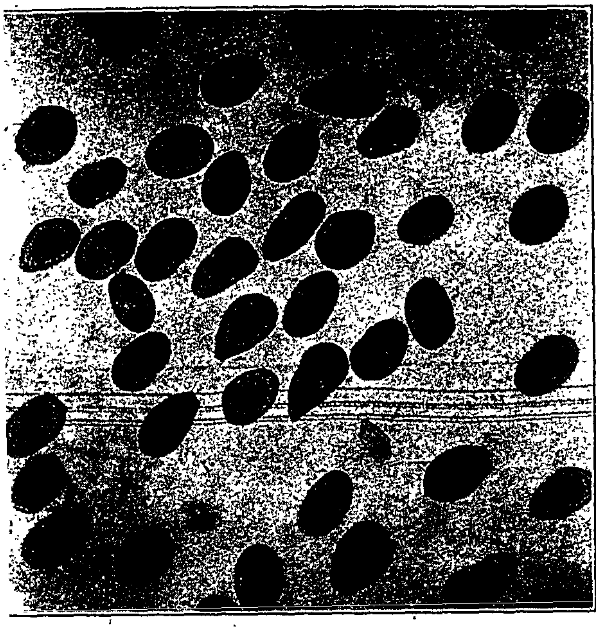

FIGURE 15
Red spores, or urediospores, of the stem rust fungus. Notice that the spores are egg-shaped and that there is no trace of any stock-cell adhering to them. When mature, these spores readily separate from the stock-cells and are thus easily spread by wind. Magnification, 275 app. (After Bailey.)

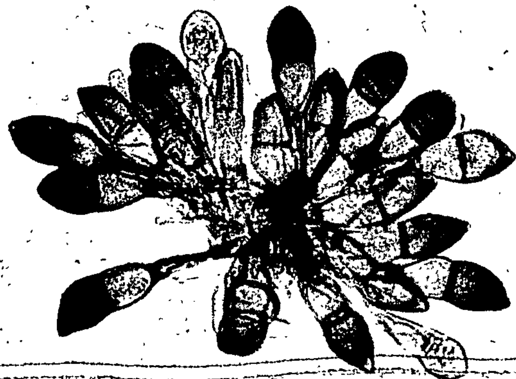

FIGURE 16
Black spores, or teliospores, of the stem rust fungus. They are two-celled and are produced on stout stock-cells. Notice the thickness of the spore-wall at the tip of the spore, and that the stock-cells adhere firmly to the spores so that the spores are not readily blown away by wind. Magnification, 300 app. (Photomicrograph by Dr. D. L. Bailey.)

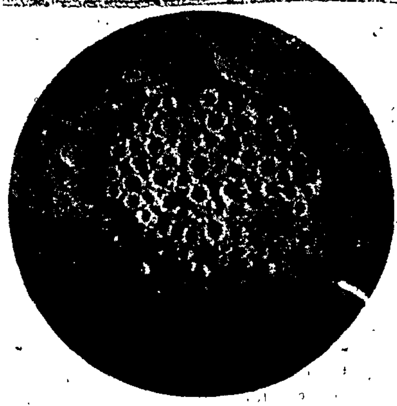

FIGURE 18
A pustule of stem rust on a barberry leaf. This is the cluster-cup, or aecial, stage of the fungus. The pustule has been enlarged to show the cup-like appearance of the aecia. Magnification, 8 app.

FIGURE 17
Common barberry, the alternate host of the stem rust fungus. As far as known, it has been completely eradicated from Manitoba and the other Prairie Provinces. (Courtesy of the United States Department of Agriculture.)

SOURCES AND SPREAD

From what has been said concerning the life cycle of stem rust, it is evident that cereal crops can only become infected by spores produced by the red stage on cereals or grasses, or by the stage on barberry. As far as known, the red stage does not survive in Manitoba from one crop season to the next crop season. In other words, the red stage present one year does not live through the winter and produce red spores which infect the crop of the following season. In regard to spores produced on barberry, it may be said that they are no longer of any consequence in this province. Between 1918 and 1923 barberry was eradicated in Manitoba (and the other two prairie provinces), so that, as far as known, there is no barberry present to become infected and to produce spores. (Of course, before barberry was destroyed, some infection did spread from it). Unless, therefore, spores are carried into the province by winds, no stem rust develops. All the evidence available points to wind-borne spores as the cause of outbreaks of the disease in Manitoba. In fact, it seems clear that, even when barberry was present, wind-borne spores were the chief cause of infection.

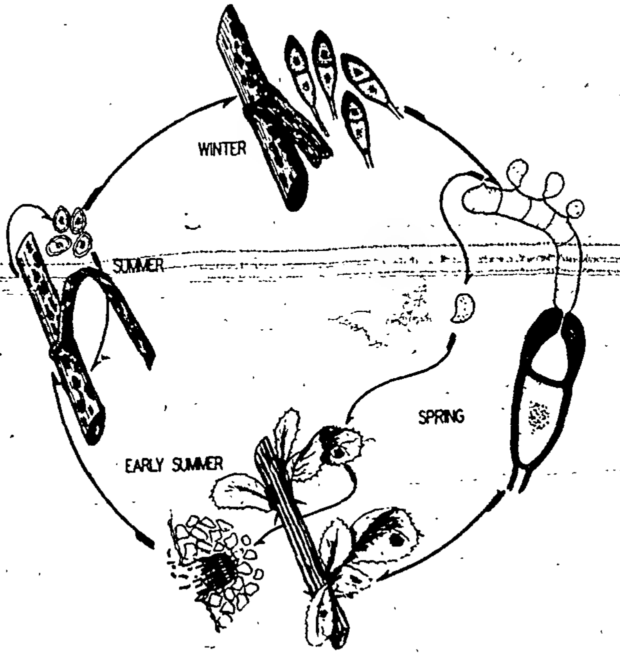

FIGURE 19
Life cycle of stem rust. The red (uredial) stage occurs on green plants. This is the stage of rapid spread. When infected crops begin to mature, the black (telial) stage appears. The spores of the black stage cannot infect cereals or grasses, but they survive the winter and germinate in the spring. On germination, they produce tiny colourless spores that infect barberry. Infections on barberry give rise to the cluster-cup stage. In the cups are produced spores (aeciospores) that infect green cereals and grasses.

It should be observed, however, that, when once infections occur in the crop, they produce spores which in turn cause other infections. Thus a few infections early in the season may be responsible for a great number of infections before the crop ripens. A new generation of spores is produced in seven or eight days, and, as one infection may produce hundreds of spores, it can be realized how rapidly the number of infections may increase. If wind-borne spores continue to arrive, as they regularly are found to do, the increase, of course, is more rapid.

The question naturally arises as to the source of the wind-borne spores that start outbreaks of stem rust in Manitoba. First, it may be pointed out that this province lies directly north, and is in fact a continuation, of the great cereal-growing belt of the United States, namely, the Mississippi Valley. In the latter area the crops ripen progressively later from south to north. Those in Manitoba ripen somewhat later than those in the States just to the south, that is, in the Upper Mississippi Valley. It can be seen, therefore, that, if an outbreak of stem rust occurs in the Mississippi Valley, there is the possibility that it may spread northward into Manitoba, for, north of the area where the outbreak occurs, there are green crops to which the spores can spread.

Two Sources of Infection. Every year, or almost every year, stem rust, in its red stage, survives the winter months in the extreme south of the Mississippi Valley, namely, in Texas, but rarely ever any farther north. In some years, such as 1935, when weather conditions are favourable for stem rust development, the disease may spread from the south throughout the entire length of the Mississippi Valley and invade Manitoba, as well as the other two prairie provinces. In other years, there is little evidence that this northward spread of the

disease has any particular influence on the amount of infection in the northern part of the Mississippi Valley, for the reason that in those years there is little stem rust development in the southern part.

In the northern part of the Mississippi Valley, barberry rusts every year, and infection spreads from it to the various cereal crops. Following the great epidemic of 1916, the destruction of barberry in this area was undertaken; but as this shrub had been widely planted as an ornamental, and as it had escaped from cultivation to a considerable extent, its eradication is not yet completed. However, there is no question that the danger from this source of infection is much less than it was formerly.

It can, therefore, be seen that the northern part of the Mississippi Valley is exposed to two sources of infection, namely, spores that blow up from the south in some years and spores arising from infected barberry every year. If weather conditions are favourable for stem rust development in the northern part, particularly in the Upper Mississippi Valley, the chances of Manitoba escaping damage from the disease are small. Weather conditions there and in Manitoba are often a good deal alike, and when conditions are favourable to the disease in one area, they are usually favourable in the other. In fact, over a period of years, in seasons when the disease was heavy, or light, in the Upper Mississippi Valley, it has been, as a rule, heavy, or light, respectively, in Manitoba. South winds blow the spores directly into Manitoba, and the heavier the infection is in the Upper Mississippi Valley, the greater are the chances of many spores being blown into Manitoba and of heavy infection occurring in this province.

VARIETIES AND RACES

Stem rust is not a simple species, but comprises several different varieties. One variety, usually referred to as wheat stem rust[1], infects wheat and barley; another variety, oat stem rust[2], infects oats; and another, rye stem rust[3], infects rye. These three varieties, although they are very similar in appearance, behave almost as if they were different rusts. This fact was well demonstrated under field conditions in 1937. In that year the wheat crop in Manitoba (except in the north and extreme west where drought was extreme) was heavily infected by stem rust, but the oats were practically free from infection; the rust on wheat did not spread to oats, for the reason that stem rust of wheat does not under ordinary conditions infect oats. In addition, there are two or three other stem rust varieties that primarily attack grasses, although the varieties on cereals also occur on certain grasses.

Mention, too, should be made of the fact that each of these varieties of stem rust comprises a number of different races. About 150 different races of wheat stem rust, 10 different races of oat stem rust, and 14 of rye stem rust are known. One race of wheat stem rust may infect certain varieties of wheat very heavily, but may only be able to infect some other varieties moderately, and some others scarcely at all. There is, therefore, a marked difference in the ability of certain races to infect a given variety of grain.

This fact explains why, for example, a variety of wheat may be resistant to stem rust in some years or in some localities and not in other years or other localities. If the races that attack the cereal variety are absent, the variety will appear to be resistant; but, if the races that attack it are present, it will be susceptible and may be severely damaged. For example, Marquis wheat is quite resistant to many of the races of wheat stem rust, and, if only those races were present in Manitoba, Marquis would be a very satisfactory variety to grow. Unfortunately, races that attack Marquis very heavily are usually present, and, consequently, Marquis is frequently badly damaged. In recent years, Durum wheat has been injured by stem rust to a greater extent than in former years, for the reason that races that attack the Durums are more prevalent now than they were some years ago.

It can, therefore, be seen that only varieties of wheat (or of barley) that are highly resistant to all races of wheat stem rust can be considered as possessing adequate resistance to the disease. For a similar reason, only oat varieties that are resistant to all the races of oat stem rust can be regarded as adequately resistant.

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(1) **Puccinia graminis** Pers. var. **Tritici** Erikss. & Henn.
(2) **Puccinia graminis** Pers. var. **Avenae** Erikss. & Henn.
(3) **Puccinia graminis** Pers. var. **Secalis** Erikss. & Henn.

EFFECT ON PLANT

Like all the other rusts, stem rust is caused by an obligate parasite. That is to say, the fungus responsible for it can only obtain food from living plant tissue. The fungus, therefore, takes from the plant the food and water which are necessary for the proper nourishment of the plant itself. Moreover, the infections destroy to a considerable extent the green colouring matter of the plant in the immediate vicinity of the infections. When infections are numerous much of the green colouring matter is destroyed, and hence the manufacture of food in the leaves and stems is seriously interfered with. The fungus, therefore, not only robs the plant of the food that the plant does produce, but it prevents it from manufacturing the amount of food that it otherwise would have been able to produce. Furthermore, the pustules of rust make many ruptures in the surface of the stems, and hence water is lost by evaporation through the ruptures, thus still further reducing the water supply of the plant. The result is that a badly rusted plant is unable to supply its kernels with an adequate amount of food and water. The kernels fail to fill, are low in protein, and, when sown, produce weak seedlings that are likely to be seriously injured by root-rotting fungi.

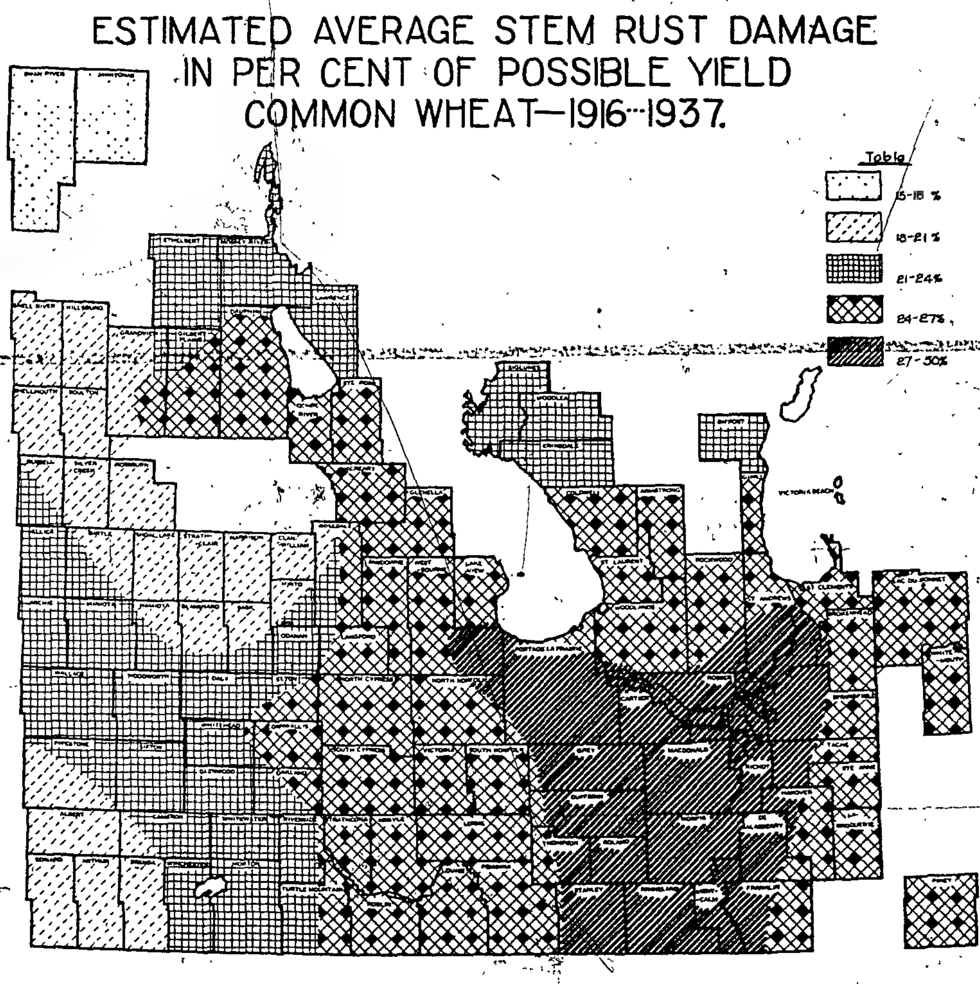

FIGURE 20

Estimated average stem rust damage to common wheat in Manitoba between 1916 and 1937, expressed in per cent. of the possible yield.

ESTIMATE OF DAMAGE

Of all the cereal rusts, stem rust has been responsible for the greatest loss to the province. This disease, as mentioned earlier, has been particularly destructive since 1916. Not all parts of the province have suffered equally from the attacks. The Red River Valley has, undoubtedly, suffered more, the Swan River Valley less, than any other part of the province. In most years, the western half of the province has been less damaged than the eastern half by the disease.

Wheat. From 1916 to 1923, practically all the wheat grown was highly susceptible to stem rust. The introduction of Durum wheat, however, had been well begun and, following the rust epidemic of 1923, the cultivation of Durums spread very rapidly. By 1928 it occupied 56 per cent. of the area sown to wheat. In more recent years, the area sown to Durums has decreased somewhat, occupying between 30 and 40 per cent. of the wheat acreage. This wheat has not been seriously injured by stem rust except in one or two of the more recent years (e.g., 1935). Its introduction has, therefore, reduced very appreciably the damage done by stem rust to wheat. Up to 1937, although one or two of the common wheats grown possessed partial resistance, their resistance did not reduce very markedly the amount of damage done by the disease.

Most of the loss has, therefore, occurred in common wheat. An estimate of the loss, expressed as a percentage of the possible yield, is presented in Figure 20. These percentages represent the average annual reduction in the yield of common wheat during the 22 year period 1916 to 1937.

In Table 4 an estimate of the loss in common wheat is given by crop districts. It will be seen that the estimated average annual total reduction in yield of common wheat amounts to 12,767,000 bushels, and that, at $1.03 per bushel—the average price for the 22 year period —the cash loss to the province becomes $13,149,682.00. For the whole period, the loss would therefore reach the enormous sum of $289,293,000.00. If the estimate for damage from leaf rust (1,940,000 bushels) is added to the one for stem rust the total rust loss becomes 14,707,000 bushels, which is probably below rather than above the actual loss. The estimate is rather close to that of Greaney (Scientific Agriculture 16: 608-613, 1936) who calculated that, for the 11 years, 1925 to 1935, the average annual loss from wheat rust (stem rust and leaf rust) in Manitoba was 15,092,000 bushels.

TABLE 4—The average annual yield of common wheat in Manitoba and the estimated annual average loss in bushels and dollars, caused by stem rust of wheat during the 22 year period 1916 to 1937, by crop districts.

Crop District	Average Annual Yield Bushels	Estimated Average Annual Loss	
		Bushels	Dollars[1]
Eastern	164,000	75,000	76,969.00
Springfield	945,000	436,000	448,846.00
Red River[2]	7,428,000	4,045,000	4,166,162.00
Mid-Lake	404,000	175,000	180,344.00
Killarney	3,356,000	1,547,000	1,593,691.00
Carberry	3,478,000	1,489,000	1,534,044.00
Neepawa	2,074,000	935,000	962,956.00
Dauphin	1,951,000	831,000	855,883.00
Western Shore	303,000	106,000	108,759.00
Melita	1,754,000	652,000	671,607.00
Virden	4,477,000	1,522,000	1,567,613.00
Russell	2,644,000	743,000	765,103.00
Swan River	875,000	211,000	217,705.00
TOTAL	29,853,000	12,767,000	13,149,682.00

(1) Average price per bushel $1.03.
(2) Includes Crop District No. 4 (Winnipeg).

According to this estimate the annual average yield of common wheat would have been, in the absence of stem rust and leaf rust, 44,560,000 instead of 29,853,000 bushels, or an average yield per acre of just under 19.5 bushels.

Oats. As a rule, in years when stem rust is heavy on wheat, it is also severe on oats. Weather conditions that are favourable for the development of the one are favourable for that of the other. Occasionally, however, oat stem rust may be very light when wheat stem rust is very heavy. This was the situation in 1937, when over the province, except along the western margin and north of the Riding Mountains, areas seriously affected by drought, wheat was badly rusted while oats were only lightly affected.

Oats apparently suffer just as severely as wheat from a heavy attack of stem rust, but the damage done is not so evident in the case of oats as it is in the case of wheat: the high proportion of hull to kernel proper in oats tends to mask the damage when expressed as reduction in bushels. A better indication of the damage in oats would be found in the weight per bushel. In the present case, the customary practice is followed and the damage is expressed as reduction in bushels.

It is estimated that, during the 22 years under review, the average annual loss in oats has not been less than 6,167,000 bushels, which, at an average price of $0.41 per bushel would make an annual cash loss of $2,528,470.00. According to calculations made by Greaney (Scientific Agriculture 16: 608-613, 1936), the average annual reduction in yield due to stem rust during the six year period 1929 to 1934 was 6,338,000 bushels.

Barley. Generally speaking, barley has been considerably less damaged than wheat or oats by stem rust. The reason for this is not that the varieties grown were resistant, but rather that, as a rule, the barley crop ripened early, and hence escaped the full force of the epidemics. Usually, in years when the stem rust attack was moderate to severe on wheat, late barley at least was seriously injured. It is estimated that, between 1916 and 1937, the average annual loss in barley due to stem rust was somewhere in the neighbourhood of 2,350,000 bushels, or, at an average price of $0.45 per bushel, $1,057,500.00.

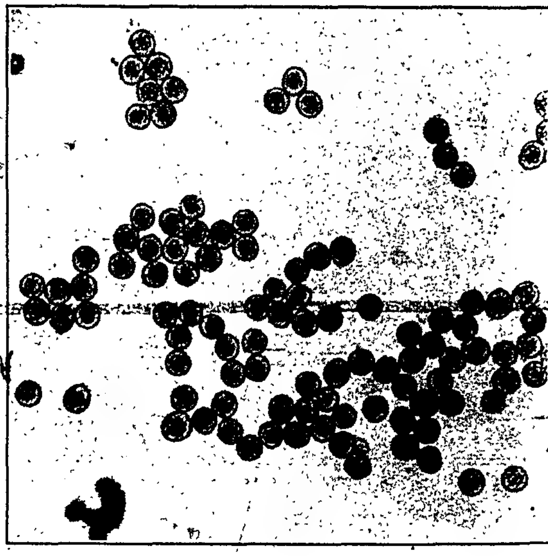

FIGURE 21
Red spores of the fungus responsible for leaf rust of wheat. The spores are mostly round, and, like the red spores of stem rust, have been completely separated from their stock-cells. They, too, are readily spread by winds. Magnification 120 app. (Photomicrograph by Mr. A. M. Brown.)

LEAF RUST OF WHEAT

As the name implies, this rust attacks principally the leaves of the wheat plant, but the leaf sheaths also may be affected. The pustules of the red stage are usually smaller and rounder than are those of stem rust, although the colour of both is similar. For this reason, one rust is sometimes mistaken for the other. The red spores of leaf rust are round (Fig. 21), while those of stem rust are egg-shaped (Fig. 15). Leaf rust of wheat is present in Manitoba every year, usually appearing some time about the middle of June. Apparently it is regularly introduced by wind-borne spores, for there is little opportunity in this province for its survival from year to year, and wind-borne spores are always present in advance of infections in the wheat crop. It increases rapidly if the weather is moderately cool and rain or dew is present to permit the spores to germinate. Hot, dry weather tends to check its development.

Occurrence in Manitoba. In Manitoba, leaf rust is not usually so severe as in some other wheat-growing areas, such as northern Europe and the central part of the United States, but it is present every year and, in some years, it has reached epidemic proportions. Information as to its prevalence between 1916 and 1920 seems not to be available. Between 1921 and 1937, heavy infection occurred in this province in 1921, 1925, 1927, 1930, 1932, 1935, and moderately heavy infection in 1923, 1924, 1931, 1934 and 1937. In the remaining years, infection was comparatively light. This rust was heavy again in 1938.

Races. As in the case of wheat stem rust, leaf rust of wheat, too, comprises a large number of races. Over ninety have now been distinguished. These races are similar in appearance, but they differ in their ability to infect different varieties of wheat. In other words, a variety of wheat may be highly resistant to some races but very susceptible to others. This fact has to be taken into account in breeding for resistance to leaf rust.

Effect on Plant. A heavy attack of leaf rust may involve practically all the leaf surface of the plants and cause the leaves to die prematurely. The leaf sheaths, too, may be similarly affected. As these parts, like other green parts of the plant, manufacture food by the aid of sunlight, it can be seen that any injury to them caused by the disease reduces the amount of food manufactured and made available for storage in the kernels. Like stem rust, leaf rust obtains its food and water supply from the plant and thereby robs the plant of such essential materials. Hence, when leaf rust is abundant, the yield is appreciably reduced in weight and volume. The quality of the grain is also lowered. The earlier in the season the disease becomes established in a crop, the greater usually is the damage suffered by it.

Factors Involved in Yield Reduction. The opinion is very commonly held that leaf rust of wheat is responsible for very little damage. This opinion is very probably based on the fact that only when the attack occurs early and severely, and soil moisture is low, is there very noticeable shrivelling of the kernels. The damage usually finds expression in other ways. Mains (Journal of Agricultural Research 40: 417-446, 1930) showed that a heavy attack of leaf rust brings about a marked reduction in yield, the reduction being due to three chief causes: (1) the tip and basal spikelets of the head often fail to set seed, (2) the average percentage of central florets setting seed is much reduced, and (3) the kernels, although probably plump in appearance, are somewhat smaller in size than are those from rust-free plants. In experiments carried out in Illinois in 1925 and 1926, he found that on a spring wheat (Illinois, No. 1) which bore a moderate to heavy infection from blossoming to maturity, the reduction in yield was just over 24 per cent.

Caldwell and co-workers (Journal of Agricultural Research 48: 1049-1071, 1934) found that, under field conditions in Illinois, leaf rust sometimes reduced the yield by more than 25 per cent. In Kansas, Johnson and Miller (Journal of Agricultural Research: 49: 955-981, 1934) found by carefully controlled experiments that leaf rust was able to reduce the yield of wheat from 42 to 93 per cent., depending on the stage of the wheat when the rust became severe. The earlier the infection became heavy, the less was the yield. They noted a marked deterioration in the root system of the heavily rusted plants, and a reduction in the percentage of protein in the flour from rusted grain. A number of other investigations could be mentioned that show very conclusively that this disease is capable of doing very considerable damage.

Estimate of Damage. It is probable that leaf rust of wheat has done more damage in Manitoba than it has ever been accused of doing. The damage, however, has been considerably less than it might have been by reason of the fact that Marquis wheat is only moderately susceptible, and Durum wheat rather highly resistant to it. Until recent years, these wheats formed the bulk of wheat crop in this province. Nevertheless, it seems safe to say that the average annual loss from leaf rust of wheat in Manitoba has been somewhere near 7 per cent. for common wheat. The loss for Durum has been almost negligible. Calculations covering the 17 year period, 1921 to 1937, indicate that the average annual loss in this province due to leaf rust has probably not been less than 1,940,000 bushels, or a cash loss of $2,225,800.00.

CROWN RUST OF OATS

The name refers to a characteristic feature of the black spores, namely, a crown-like formation at the tip of each spore (Fig. 22). This rust attacks the leaves and leaf sheaths of oats. It does not attack wheat, barley or rye. It can be distinguished from oat stem rust by the orange colour of the spots, or pustules, on the plants. (Stem rust pustules are red). The third stage of this rust occurs on buckthorn, and spores produced on infected buckthorn spread to oats. The relation between crown rust and buckthorn is similar to that between stem rust and barberry, already discussed. In applying to crown rust the description given of that relation, it is only necessary to substitute the words crown rust for stem rust, and buckthorn for barberry. This rust comprises a number of different races, just as do wheat stem rust, oat stem rust, or leaf rust of wheat. Altogether, 45 races of crown rust are known at present to occur in North America. In breeding for resistance to crown rust, the existence of these races must be taken into account. A new variety of oats should at least have high resistance to the commonly-occurring races.

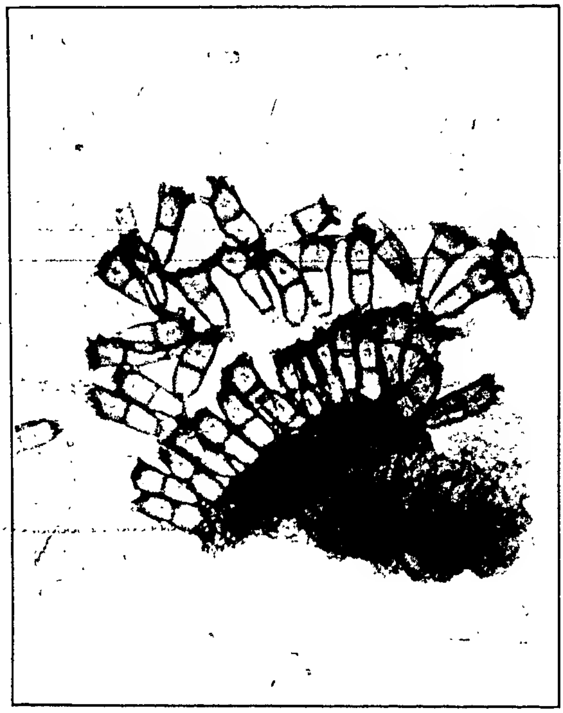

FIGURE 22
Black spores, or teliospores, of the crown rust fungus. Notice that they are two-celled and that at the top of each spore are projections that form a "crown." Magnification, 200 app. (Photomicrograph by Mr. A. M. Brown.)

Occurrence in Manitoba. Only rarely is crown rust very destructive in Manitoba. An epidemic occurred in 1927 and again in 1935. There was one also in 1938. This rust was moderately severe in 1923, and caused some damage to oats in 1922 and 1932. Whether or not it was prevalent in 1916 is not known. As a rule, it has occurred in severe form in years when stem rust has been severe. In most of the other years it has been of minor importance. Not infrequently fields of oats in the neighbourhood of buckthorn hedges have been badly rusted, but no serious attempt has yet been made in this province to eradicate buckthorn. Severe and widespread attacks are apparently caused largely by wind-borne spores from the south. The effect of this rust on oats is similar to that of stem rust.

Estimate of Damage. It is estimated that in 1927 crown rust caused a loss of 5,656,000 bushels, and in 1935 a loss of 5,786,000 bushels. Probably since 1916 it has caused altogether a loss to this province somewhere in the vicinity of 17,000,000 bushels of oats.

LOSSES DUE TO LOW GRADE

Not only do these rusts cause a loss in yield, but they also cause a loss in grade. Especially is this true of stem rust. In bad rust years, much of the wheat crop, for instance, falls below requirements of the standard grades, and special grades have to be established for such grain. Not a little of it may be graded as low as "Feed" wheat. The spread in price between Nos. 1 and 2 Northern and the special grades and Feed is usually quite marked. Similarly, with oats and barley, a rusted crop produces low yield and a poor grade of grain.

PLANT DISEASES IN RELATION TO COST OF CROP PRODUCTION

Production costs are always a heavy charge against any crop. If the yield is high, the production cost per bushel is low, whereas, if the yield is low, the production cost per bushel

is high. Owing to the ravages of plant diseases in certain crops, the yield of these crops has been very markedly reduced, and, consequently, the cost of producing them has been considerably higher than it would have been in the absence of disease. For example, between 1916 and 1937, stem rust and leaf rust of wheat, according to the estimate already given, reduced the yield of wheat in Manitoba on an average each year 14,707,000 bushels. At an average yield of 19.5 bushels per acre, this quantity of wheat would require 754,205 acres of land for its production. To seed this area at the rate of one and one-half bushels per acre would require 1,131,307 bushels of seed. Consequently, it may be considered that the rusts increased the cost of production each year by an amount equivalent to the cost of the following items: (1) considerably over one million bushels of wheat seed, (2) farm operation necessary to the cultivation, sowing, and reaping of over three-quarters of a million acres, and (3) depletion of soil fertility over that acreage to the extent necessary to produce an average crop of wheat.

If the two rusts had been absent, all this cost could have been saved, without any reduction in the amount of wheat produced. Not only would the amount have been just as much, but the quality would have been better, and, very probably, the value of the crop would have been higher.

In like manner, the cost of producing oats and barley has been much greater than it otherwise would have been if stem rust and crown rust of oats, and stem rust and leaf rust of barley did not exist. Similarly, with the other field crop diseases, each disease increases the cost of producing the crop that it attacks. The heavier the attacks and the more frequently they occur, the greater is the increase in production costs.

PROGRESS IN PLANT DISEASE CONTROL

Control of plant diseases may be effected to a greater or less extent along three different lines, namely, through cultural practices, through various preventive treatments, and through the use of disease-resistant varieties. Efforts to control diseases are, of course, not necessary against those diseases that are not present, and it is to the credit of the small but efficient corps of inspectors that such diseases as flag smut of wheat and black wart of potatoes have been so far excluded from Canada.

CULTURAL PRACTICES

Centuries of experience and, in recent years, careful experimentation have furnished some very reliable general recommendations concerning the growing of crops. Proper preparation of the soil, the use of clean uninjured seed, crop rotation, the application of barn yard manures, and, in later years, of artificial fertilizers, etc., are not at all new farm practices, but in the last few years they have taken on a new significance as their value in the control of root rot diseases becomes better understood.

Maintaining Tilth. It is now well established that a cereal plant for instance, growing in well prepared, fertile soil is less severely damaged by common root rot organisms than is a plant growing in an ill prepared or unfertile soil, and that, even if it does become infected, it has a much better chance of surviving than has the plant growing under poor soil conditions. In other words, the better the physical conditions for growth, the better, are the chances of the plant producing a good yield in spite of root rot infection.

Crop Rotation. Recent investigations have shown that crop rotation tends to hold in check root rot development, while two or more successive sowings of the same crop in the same soil tends to permit the amount of infection to increase. An approved rotation of crops is the chief recommendation made in Western Canada for the control of take-all root rot,

true of shrunken or discoloured seed. Sound healthy plump kernels produce vigorous seedlings, which, in turn, are better able than seedlings from injured, shrunken or diseased seeds, to become established quickly in the soil and to undertake an independent existence. Consequently, such seedlings are considerably less subject to seedling-blight injury than are the less vigorous seedlings.

Use of Fertilizers. The use of fertilizers has not yet become a general farm practice in field crop production in this province. In recent years, however, it has been found that, under certain conditions, root rot damage to cereal crops can be reduced considerably by the application of the proper fertilizer.

Common root rot tends to be more severe in crops grown in light sandy soils, in exhausted soils, and in soils of high salt content, than in crops grown in better soils. The roots become infected, and the damaged root system is then less able than it otherwise would be of sustaining normal plant growth. Fertilizers, by providing a readily available food supply for the plants, tend to keep them better nourished and hence less subject to root rot damage. Even although considerable infection may occur, the plants are able to develop better than if no fertilizer was present.

A very clear case of the value of fertilizer applications is that of browning root rot of wheat. It is caused by a parasitic fungus, but it occurs almost entirely in soils low in phosphorus. The disease can be largely prevented by the use of phosphate fertilizers. Or, again, damage from common root rot in alkaline soil can be markedly reduced by the addition of acid fertilizers or barn-yard manure to such soil.

Rogueing. Another farm practice that is gradually becoming of importance in the control of certain diseases is the rogueing out of diseased plants or diseased plant parts and destroying them as soon as they are observed. This method has given good results with different virus diseases, with the loose smuts of cereals, and with corn smut. In the latter disease the smut galls are removed from the affected plants.

PREVENTIVE TREATMENTS

Under this heading may be considered any advancement in the control of field crop diseases by artificial means, such as seed treatments and the application of fungicides to the growing plants. What means are used in any particular disease depends largely on how the disease is transmitted. Some diseases are carried either on or in the seed or in both ways, others in the soil, still others in the air, and most of the virus diseases by insects.

Hot Water Treatment. Against diseases that are carried within the seed, surface disinfection of the seed is apparently of no value as a means of controlling them. Some treatment is necessary that will destroy the organism responsible for the disease but that will not seriously injure seed germination. The hot water treatment for such diseases as loose smut of wheat and loose smut of barley is the only one yet known to be effective. Within recent years many efforts have been made to reduce the risk of seed injury from heat by adding various chemicals to the water, with the hope that satisfactory control could be obtained at a somewhat lower temperature Unfortunately, all such attempts have produced little or no practical improvement. Seed disinfection by dry heat has not been found satisfactory, as seed germination is usually seriously reduced by a temperature that is high enough to kill the fungus within the seed.

Fungicides. A fungicide must not only be capable of controlling the disease or diseases against which it is used, but it must be relatively harmless to the plant or plant parts with which it comes into contact. Furthermore, it must be inexpensive and it must be easily applied. If it is effective against several diseases it is more likely to find favour with users than if it is effective against only one or two. An improvement in any one, or in more than one, of these respects gives a fungicide possessing it an advantage over another one that lacks it, provided, of course, that the two are equally good in other respects.

Fungicides used for seed disinfection illustrate this tendency. "Blue stone" (copper sulphate) solution was extensively replaced by formaldehyde, partly because formaldehyde was already in solution and hence more easily prepared, but mostly because it was less injurious as a seed treatment. When it was discovered that copper carbonate dust is effective against bunt of wheat, and caused little if any seed injury, it became rather extensively used to control bunt. As it is not effective against covered smut of barley and the two smuts of oats, its use was soon discontinued when organic mercury dusts were found to be even more effective than copper carbonate against bunt. Besides, the organic mercury compounds have the added advantage that they give almost perfect control of the other three smuts as well. As a matter of fact, they are effective against a large number of diseases that are carried externally on seed.

Sulphur dust as a fungicide for the control of plant rusts has only been made use of in recent years. Owing to the fact that in field crops the area to be protected against rust attack is usually very great, protection of the whole crop by means of sulphur dust becomes all but impossible. Protection of limited areas, however, is quite practical. This method of prevention, like all other artificial ones, adds to the cost of production; but, if no other method of rust control were at hand, there seems to be little doubt that sulphur dusting for the control of wheat stem rust would become adopted to some extent at least.

Unfortunately, most of the fungicides now in use are poisonous to man and beast, and hence in using them, precautions must be taken against poisoning. It would be a much-needed advance if a first-rate fungicide could be prepared that would not be injurious to man and animals.

PRODUCTION OF DISEASE RESISTANT VARIETIES

Everyone recognizes that the simplest and most effective method of controlling plant diseases, and thereby reducing losses caused by them, is to grow disease-resistant varieties. Market requirements, however, demand a certain standard of quality, and, unless the varieties grown reach that standard, they are of little commercial value. These standards have sprung up without reference to the plant disease problems involved in the production of varieties of the quality required.

In most of the common agricultural crops, there are varieties possessing high resistance to disease, but these varieties do not generally come up to market standards and are, therefore, not profitable to grow. On the other hand, most of the commonly occurring varieties of high commercial value are usually very susceptible to one or more diseases. In order, therefore, to obtain disease resistance and high quality in any single variety, it is usually necessary to combine by plant-breeding methods the resistance of a poor quality variety with the good quality of a susceptible variety.

Plant Disease Aspects Involved. This apparently simple procedure is, in reality, quite complicated, and very often involves a great deal of difficulty. In the first place, most disease-producing organisms comprise a number of different races or strains that differ in their ability to attack any particular variety. A variety may be highly resistant to one or more races but completely susceptible to other races of the same organism. Methods have to be devised by which the different races or strains can be distinguished one from the other. Numerous varieties of the crop concerned must be tested to discover what ones, if any, possess any marked resistance; and, if some are found resistant, to determine to what race or races they are resistant. One variety may be found to have resistance to certain races, another variety to have resistance to some other races, a third variety to have resistance to still other races, and so on. Unless high resistance to all races is present in one variety, it is necessary to bring together, by plant breeding methods, the resistances of two or more varieties in a new variety. In fact, even when high resistance to all races of the disease is found in some poor-quality variety, it may not be possible, or at any rate not easily possible, to transfer all of its resistance to a new variety.

In crossing a resistant variety of poor quality with a variety of good quality, it not infrequently happens that some objectionable character tends to be carried over along with the resistance of the poor variety into the new variety. The new variety is then undesirable in respect to the objectionable character. This character may be, for instance, susceptibility to some other disease, or some growth or quality defect, which would render the variety unsuitable for cultivation. Defects of this kind have to be eliminated, or the variety is of no commercial use New productions must be tested thoroughly over a period of years to ensure that they are not unduly susceptible to diseases other than the one against which resistance is desired.

It can, therefore, be realized that breeding for resistance to any one disease is a long and involved process. For instance, after a great deal has already been discovered regarding the different races of stem rust and the resistance or susceptibility to them of numerous wheat varieties, it requires upwards of fifteen years to produce a variety of wheat resistant to stem rust Resistance to one disease does not confer on any variety resistance to another disease, although it sometimes happens that one variety may possess resistance to more than one disease. When resistance to two or more diseases has to be secured from more than one variety, the breeding problem becomes more complicated and progress is slower.

Extensive Research in Progress. When it is remembered that it was only at the opening of the present century that the laws, or principles, governing inheritance were discovered (or rather rediscovered, as they were first announced in 1865), and that, following that discovery, years of exploratory work were spent in ascertaining the applicability of these principles to the breeding behaviour of different types of cultivated plants, it is not surprising that the first fruits of many plant-breeding endeavours are only within the last few years becoming evident.

Undoubtedly plant breeding for disease resistance holds vast possibilities for the control of plant diseases. In practically every country plant breeding for disease resistance is now being actively carried on, involving many different crops and resistance to many different diseases. Never before in the history of agriculture have so many varieties of different kinds of crop plants been available for parent material as at the present time. It is to be expected that, as time goes on, susceptible varieties of different crop plants will be replaced by resistant varieties of equally good or better commercial value.

Resistant Cereal Varieties Available. In Manitoba the need of disease-resistant cereals has been very pressing, especially the need of common wheat varieties that would be resistant to stem rust. That need is now being supplied. Three common wheat varieties that are highly resistant to stem rust have already been distributed, namely, Thatcher, Renown and Apex A few observations relative to their disease resistance or susceptibility may be made about each of them.

Thatcher was developed at the University of Minnesota, and is the result of the double cross (Marquis x Kanred) x (Marquis x Iumillo). It is highly resistant to stem rust, but very susceptible to leaf rust and is, therefore, liable to suffer damage when this disease is severe. It is resistant to loose smut but susceptible to bunt, or covered smut. It is more resistant to root rot than Marquis, and is affected to little or no extent by false black chaff.

Renown was developed at the Dominion Rust Research Laboratory, Winnipeg, from a cross between Reward and H-44-24. It is somewhat more resistant than Thatcher to stem rust, and is practically resistant to bunt and moderately resistant to loose smut. It has approximately the same resistance as Marquis to root rot. It is susceptible to false black chaff. When distributed, it was not pure for leaf rust resistance—about half of the plants were resistant, about half were susceptible. The recently-produced pure strains of Renown, however, are resistant to leaf rust and these strains will eventually replace the older stock

Apex was developed at the University of Saskatchewan, Saskatoon, from the triple cross (H-44-24 x Double Cross) x Marquis (Double Cross is the cross from which Thatcher originated). Apex is highly resistant to stem rust, and has considerable resistance to loose smut

It is moderately resistant to bunt, but moderately susceptible to leaf rust. It has about the same resistance as Marquis to root rot. It is somewhat more susceptible than Renown to discoloration from false black chaff.

In addition to the wheat varieties just mentioned, there are now available two rust resistant varieties of oats, namely, Anthony and Vanguard. Anthony was produced at the University of Minnesota from the cross (Victory x White Russian), and was introduced into Manitoba several years ago. Vanguard was produced at the Dominion Rust Research Laboratory, and distributed in 1936. These two varieties are resistant to the commonly-occurring races of oat stem rust, but not to all of the races. They are both susceptible to crown rust. To loose smut and covered smut of oats, Anthony is very susceptible, while Vanguard is moderately resistant.

Up to the present no very satisfactory rust resistant variety of barley is yet available. Peatland, a variety produced by selection from "Switzerland," a Manchurian type, at the University of Minnesota, and introduced in recent years into Manitoba, is highly resistant to stem rust, but it does not yield as well as some of the standard barley varieties, except in years when stem rust is severe. Work is progressing at the Brandon Experimental Farm and the University of Manitoba on the production of barley varieties of high stem rust resistance and good agronomic characters, and, as a number of strains are now well along in the tests, it may be expected that satisfactory varieties will be available for distribution in the not too distant future.

PROSPECTS OF PLANT DISEASE CONTROL

In conclusion, it may be stated that the prospects of controlling diseases of field crops have never been better. At no time in the history of agriculture have the problems involved in the control of these diseases been so well understood, or have so effective measures been available against them. More, too, is known than ever before concerning the life processes of plants, the effect on these processes of weather and soil conditions, and farm practices, and how these conditions and practices influence the development of plant diseases. Efficient fungicides are available and they are relatively easy of application. Of course, fungicides are not necessary if resistant varieties can be grown.

Distinct progress has been and is being made in the development of resistant varieties. Within the last two or three years varieties of common wheat have been distributed that are highly resistant to stem rust and have considerable resistance to one or more other diseases. As pointed out already, these wheats must only be regarded as the first fruits of this line of endeavour. In all probability, varieties of equally good or better agronomic and commercial qualities, and possessing a greater range of disease resistance, will, in time, displace the ones now recently distributed. The same is true in respect to oats. In fact, it seems only a matter of time, probably of relatively few years, when oat varieties resistant to stem rust, crown rust, and the two oat smuts will be available for distribution. Rust resistant varieties of barley will very probably be available within very few years. As noted earlier, varieties of flax resistant both to wilt and to rust are now being grown in the province. It is to be expected that varieties of corn both resistant to smut and suitable for Manitoba conditions will eventually be developed. All in all, there is very good ground for anticipating that the loss from plant diseases in Manitoba will be much less in the future than it has been in the past.